**Technical Paper** **No. 15**
**Revision 3**

# APPROVED PROTECTIVE CONSTRUCTION

**Approved for public release; distribution is unlimited.**

**Department of Defense Explosives Safety Board**
**Alexandria, VA**

**May 2010**

# FOREWORD

Technical Paper (TP) 15 is a record of historically significant information about the origin and evolution of protective construction designs and the explosives safety criteria associated with them. The Department of Defense Explosives Safety Board (DDESB) will keep this document current, and it will be improved and updated as new protective construction is approved and as additional information is received.

Producing a document like DDESB TP 15 requires a tremendous amount of effort and time. We are indebted to Eric Deschambault of the DDESB Staff for collecting and consolidating the information and developing the initial DDESB TP 15 in February 2001 and for keeping it current since.

The following are the more significant changes associated with Version 3:

Chapter 1:
* Introduction of the Naval Facilities Engineering Command's (NAVFAC) Whole Building Design Guide (WBDG) website that includes a webpage dedicated to ammunition and explosives (AE) storage magazines and which complements TP 15's Appendix (AP) 1 magazine listings.
* Incorporation of minimum DDESB requirements for protective construction designs/modifications that are submitted as part of explosives safety site plans.

Chapter 2:
* Information added describing expanded use of the non-propagating wall (NPW) technology and sympathetic detonation (SD) criteria in new magazine designs.
* Included the minimum earth-covered magazine (ECM) design considerations and blast loads approved by the 316th DDESB in 2000. Those loads were added in conjunction with the introduction of structural hardness designation for ECM.
* Expanded on latest Sensitivity Group (SG) and Non-propagation wall (NPW) efforts.

Chapter 3/4:
* Included a brief discussion of ECM designs that have utilized NPW.

Chapter 5:
* Added information pertaining to underground criteria found in North Atlantic Treaty Organization (NATO) Allied Ammunition Storage and Transport Publication (AASTP)-1.

Chapter 6:
* Updated barricade information pertaining to DDESB approved changes associated with the two (2) degree rule for determining barricade height.
* Included the significant work performed by NATO Nations regarding the use of sand-filled, fabric, wire-reinforced barricades to prevent prompt propagation.
* Updated information related to Munitions and Explosives of Concern (MEC) Removal Sites to reflect currently approved methodologies for determining safe distances from sites storing and disposing of such items.

* Expanded on improvements made to the Buried Explosion Module (BEM).

* Incorporation of DDESB approved water barricades for separating combat aircraft and reducing default intermagazine (IM) distances.

* Expanded on DDESB approvals of Transportable Controlled Detonation Chamber-Models T-25, T-30 and T-60 and other contained detonation vessels.

Chapter 8: * Title revised to reflect a move from just addressing hardened aircraft shelters (HAS) to a broader area related to airfield associated protective construction, to include mitigation methods developed to reduce MCE associated with aircraft munitions.

* Expanded HAS information to address the significant efforts undertaken by DDESB and the Air Force Safety Center (AFSC) to address missing criteria associated with HAS.

* Incorporated Noble Eagle F-15 and F-16 missile load MCEs and reduced quantity distance (QD), which previously were only found in AP-2.

* Added DDESB approvals for reduced MCE and QD for AIM-7, AIM-9, and AIM-120 container storage, as well as certain missile trailer configurations.

Chapter 9: * This new chapter was added to address other non-storage related protective construction. Adding other approved facility designs into this chapter will be a focus area for Revision 4 of TP 15.

APPENDICES

AP-1: * Tables contained in AP-1 were: (a) updated to incorporate new magazine designs approved by the DDESB since Version 2 was published in June 2004, (b) add older designs which did not make it in Version 2, and (c) add any new information for designs already in AP-1.

AP-2: * Information was updated to incorporate new and approved protective construction designs for operational (deployed) storage and airfield applications and to introduce NATO AASTP-5, which addresses deployed operational storage and which was ratified by the DDESB in 2008, following Service coordination.

Curtis Bowling
Chairman, DDESB

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## Tables



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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AAP | Army Ammunition Plant |
| AASTP | Allied Ammunition Storage and Transport Publication |
| AE | Ammunition and Explosives |
| A/E | Architectural/Engineer |
| AEC | U.S. Army Engineer Corps (preceded Corps of Engineers) |
| AF or USAF | United States Air Force |
| AFB | Air Force Base |
| AF-NGB | Air Force, National Guard Bureau |
| AFSC | Air Force Safety Center |
| AFSSG | Air Force Special Study Group |
| AFWL | Air Force Weapons Laboratory |
| AG | Aboveground |
| ALCM | Air Launched Cruise Missile |
| ANESB | Army Navy Explosives Safety Board (**NOTE**: JANASB renamed to ANESB on 2 May 1945) |
| ANFO | Ammonium Nitrate and Fuel Oil |
| ANG | Air National Guard |
| AOC | Atlantic Ordnance Command |
| AP | Appendix |
| APCN | Air Pollution Control Unit |
| ARL | Army Research Laboratory |
| ASET | Aircraft Shelter Explosive Test |
| ASP | AGAN Steel Panel |
| ASESB | Armed Services Explosives Safety Board (**NOTE**: ANESB was renamed to ASESB on 16 September 1948) |
| ATD | American Table of Distances, published by The Institute of Makers of Explosives (IME) |
| | |
| BOD | Basis of Design |
| BEM | Buried Explosion Module |
| BFR | Blast and Fragment Resistant |
| BOD | Basis of Design |
| BRL | Ballistics Research Laboratory (**NOTE**: Now the Army Research Laboratory (ARL)) |
| | |
| CBU | Cluster Bomb Unit |
| CDC | Contained Detonation Chamber |
| CINCPACAF | Commander-in-Chief, Pacific Air Force |
| COE | U.S. Army Corps of Engineers |
| CONEX | Container Express |
| | |
| DA | Department of the Army |
| DAC | U.S. Army Defense Ammunition Center |
| DASA | Defense Atomic Support Agency |

| | |
|---|---|
| DBC | Donovan Blast Chamber |
| DDESB | Department of Defense Explosives Safety Board (**NOTE**: ASESB renamed to DDESB on 23 October 1971) |
| DLA | Defense Logistics Agency |
| DNA | Defense Nuclear Agency |
| DoD | Department of Defense |
| DDESTSG | DoD Explosives Safety Testing Steering Group |
| DOT-E | Department of Transportation - Exemption |
| | |
| EB | Enclosed Barricade |
| ECD | Explosive Containment Device |
| ECM | Earth-Covered Magazine |
| EDS | Explosive Destruct System |
| EOD | Explosive Ordnance Disposal |
| EOD RSL | EOD Ready Service Locker |
| ES | Exposed Site |
| ESKIMO | **E**xplosive **S**afety **K**nowledge **IM**provement **O**peration |
| ESQD | Explosives Safety Quantity Distance |
| ESS | Explosives Safety Submission |
| ESTC | Explosives Storage and Transportation Committee |
| EUR | Europe |
| | |
| FAA | Federal Aviation Administration |
| FD | Field Distance |
| FOB | Forward Operating Base |
| FM | Factory Mutual |
| FRELOC | Unknown acronym. (**NOTE:** This was the designation given by U.S. Army Engineer Command, Europe to a specific ECM design of the mid-1970s, 33-15-13, a modified Stradley design) |
| FSTS | Forward Storage Site |
| | |
| GOJ | Government of Japan |
| | |
| HAS | Hardened Aircraft Shelter |
| HAZMAT | Hazardous Material |
| HD | Hazard Division |
| HFD | Hazardous Fragment Distance |
| HEST | High Explosive Simulation Test |
| HP-2B | High Performance – 2 Bay |
| HP-3B | High Performance – 3 Bay |
| HPM | High Performance Magazine |
| HSILS | High Security Integrated Locking System |
| | |
| IAW | In Accordance With |
| IBD | Inhabited Building Distance |
| ILMF | Intermediate Level Maintenance Facility |

| | |
|---|---|
| IMD | Intermagazine Distance |
| IME | Institute of Makers of Explosives |
| ISO | International Organization for Standardization |
| | |
| JBA | Joint Board on Ammunition (**NOTE**: Established 2 July 1928. This was the Board assigned to review storage conditions within the military, following the Lake Denmark accident in 1926). |
| JANMB | Joint Army Navy Munitions Board (**NOTE**: Established 6 August 1928. This was the name of the first Board established by the Secretaries of the War and Navy to advise them). |
| JANBAS | Joint Army and Navy Board on Ammunition Storage (**NOTE**: JANMB was renamed to JANBAS on 20 August 1930. On 22 January 1942, the Board was renamed to Joint Army and Navy Board of Ammunition Storage). |
| JANASB | Joint Army Navy Ammunition Storage Board (**NOTE**: The JANBAS was renamed to JANASB on 24 March 1943). |
| JED | Japan Engineer District, Corps of Engineers |
| JHCS | Joint Hazard Classification System |
| | |
| MCAS | Marine Corps Air Station |
| MCE | Maximum Credible Event |
| MCLB | Marine Corps Logistics Base |
| MEC | Munitions and Explosives of Concern |
| MFD | Maximum Fragment Distance |
| MGFD | Munition with the greatest fragment distance |
| MIL-BUL | Military Bulletin |
| MILCON | Military Construction |
| MILVAN | Military-Owned Demountable Containers |
| MK | Mark |
| MLH | Munitionslagerhause (**NOTE**: German word for munitions storage magazine) |
| MOD | Ministry of Defence |
| MOFB | Miniature Open Front Barricade |
| MPB | Missile Processing Building |
| MPM | Most Probable Munition |
| MRM | Modular Ready Magazine |
| MSD | Minimum Separation Distance |
| MSM | Modular Storage Magazine |
| MTC | Missile Test Cell |
| MWB | Mineral Water Bottle |
| | |
| N/A | Not Applicable |
| NAS | Naval Air Station |
| NASA | National Aeronautical and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NAVFAC or | Naval Facilities Engineering Command |

| | |
|---|---|
| NAVFACENGCOM | |
| NAVFAC ESC | Previously known as NFESC or NCEL |
| NAVSEASYSCOM | Naval Sea Systems Command |
| NAWS | Naval Air Warfare Station |
| NAWC | Naval Air Warfare Center |
| NCEL | Naval Civil Engineering Laboratory (**<u>NOTE</u>**: Now known as Naval Facilities Engineering Service Center) |
| NEW | Net Explosive Weight |
| NFESC | Naval Facilities Engineering Service Center (now NAVFAC ESC) |
| NGB | National Guard Base |
| NMERI | New Mexico Engineering Research Institute |
| NOSSA | Naval Ordnance Safety and Security Activity |
| NOTS | Navy Ordnance Test Station (**<u>NOTE</u>**: Now known as Naval Air Warfare Center, China Lake, CA) |
| NPW | Non-Propagation Wall |
| NRL | Naval Research Laboratory |
| NSWC | Naval Surface Warfare Center |
| | |
| OCE | Office Chief of Engineers (U.S. Army) |
| OCO | Office of the Chief of Ordnance |
| ODC | On-site Demolition Container |
| OE | Ordnance and Explosives |
| OFB | Open Front Barricade |
| OQMG | Office of the QuarterMaster General |
| | |
| PACAF | Pacific Air Force |
| pcf | pounds-per-cubic-foot |
| PES | Potential Explosion Site |
| PTRD | Public Traffic Route Distance |
| | |
| QD | Quantity Distance |
| QRS | Quick Reaction Site |
| | |
| RC | Reinforced Concrete |
| RCWM | Recovered Chemical Warfare Materiel |
| RSL | Ready Service Locker |
| | |
| SD | Sympathetic Detonation |
| SDW | Substantial Dividing Wall |
| SG | Sensitivity Group |
| SNL | Sandia National Laboratory |
| STD | Standard |
| SUBASE | Submarine Base |
| | |
| TDP | Technical Data Package |
| TM | Technical Manual |

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|---|---|
| TNT | Trinitrotoluene |
| TOW | Tube-Launched, Optically-Tracked, Wire-Guided |
| TP | Technical Paper |
| TRANSCOM | Transportation Command |
| | |
| UL | Underwriters' Laboratory |
| UNK | Unknown |
| USADACS | United States Army Defense Ammunition Center and School (**NOTE**: Now known as Defense Ammunition Center (DAC), located at McAlester, OK.) |
| US | United States |
| USAESCH | U.S. Army Engineering and Support Center, Huntsville |
| USATCES | U.S. Army Technical Center for Explosives Safety (**NOTE:** Part of DAC) |
| USAF or AF | United States Air Force |
| USAFE | United States Air Forces, Europe |
| USAREUR | U.S. Army, Europe |
| UXO | Unexploded Ordnance |
| | |
| VSS | Vented Suppressive Shield |
| | |
| WBDG | Whole Building Design Guide |
| WPNSTA | Weapon Station |
| WSA | Weapon Storage Area |
| WW | World War |
| | |
| Y & D | Bureau of Yards and Docks (**NOTE**: Former name of NAVFAC) |

# C1. **CHAPTER 1**

## **INTRODUCTION**

### C1.1. **GENERAL**.

C1.1.1. DDESB Technical Paper (TP) 15 provides a comprehensive listing of ammunition and explosives (AE) storage facilities and protective construction facilities and features that have been designed and built over the past 80 years. Its purposes are to: (1) educate and enhance from an historical perspective, an understanding of how criteria developed and were influenced; and (2) to document approved protective construction designs to provide the explosives safety community common information for their use and benefit. It accomplishes this by documenting:

(a) Significant testing that has been performed, and that has impacted the development and evolution of explosives safety criteria found in reference 1-1,

(b) Past and present protective construction design information.

(c) Relevant siting information associated with each protective construction facility and feature.

C1.1.2. Throughout TP 15, safety distance is calculated primarily by means of the formula $\mathbf{D = K \bullet W^{1/3}}$, where "**D**" is the distance in feet, "**K**" is a factor depending upon the risk assumed or permitted, and "**W**" is the NEW in pounds. This is further described in Chapter 2 of Reference 1-1. Distance requirements determined by the above formula are sometimes expressed by the value of "**K**", using the terminology K9, K11, K18, to mean K = 9, K = 11, and K = 18. In certain cases, safety distances have been determined by means of testing, such as with a full or partial containment of explosion effects (e.g., blast, thermal, primary fragments, structural debris). When this is the case, a description of the test and the results of testing will be provided.

C1.1.3. TP 15 will be updated periodically by adding information on existing items contained therein and to expand it to address new protective construction areas, as deemed necessary.

C1.1.4. Appendices AP1 and AP2 will be maintained and kept current without re-issuing TP15. The updates will be re-published at the DDESB's webpage http://www.ddesb.pentagon.mil.

C1.1.5. Where additional information or explanation is considered important or relevant, an editor's note is provided. This information is identified as follows: [**Note**:].

C1.2. **SUMMARY OF DDESB TP 15 CONTENT.** The following descriptions provide a brief summary of the content of each chapter.

C1.2.1. Chapter 2 provides a history of the evolution of magazine design since the Lake Denmark accident of 1928 and the significant testing that has been conducted as part of this evolution that has impacted magazine design and magazine siting criteria.

C1.2.2. Chapter 3 addresses the major differences between 7-Bar, 3-Bar, and Undefined ECM and describes the typical features and structural components associated with each type. Chapter 3 also includes a discussion of storage magazines and transportation containers that have been specifically approved with reduced net explosive weight (NEW) and/or reduced QD.

C1.2.3. Chapter 4 provides information associated with the four magazine tables found in Appendix AP1. Those tables list ECM, as well as those magazines and transportation containers that have reduced QD or reduced MCE, identified to date and relevant information for each design.

C1.2.4. Chapter 5 pertains specifically to underground (tunnel) AE storage facilities and criteria associated with them.

C1.2.5. Chapter 6 provides a comprehensive discussion of available barricade designs, fragment distance-limiting barrier designs, test cells, detonation chambers, suppressive shields, and other similar protective construction, that have been approved for use by the DDESB and pertinent testing and information related to each item.

C1.2.6. Chapter 7 describes the history and testing associated with barricaded module development and their use for AE storage.

C1.2.7. Chapter 8 documents the history and testing of hardened aircraft shelters (HAS).

C1.2.8. Chapter 9 addresses non-storage related protective construction. It currently contains little information and its expansion will be a priority for Revision 4 of TP15.

C1.2.9. Appendix AP1 contains Tables AP1-1 through AP1-4, which are discussed in Chapter 4. Supporting information, as appropriate, are included in the tables.

C1.2.9.1. Table AP1-1 identifies 7- and 3-Bar ECM designs approved for new construction. These are designs that are being maintained by DoD Components and that are kept current with explosives safety criteria (e.g., explosives safety, construction, specifications).

C1.2.9.2. Table AP1-2 lists existing 7- or 3-Bar ECM designs that users may find in the field. These designs are no longer maintained and will more than likely not reflect current criteria. [**NOTE:** These designs can be considered for new construction, as approved on a case-by-case basis by the DoD Component, provided the designs have been thoroughly reviewed and the design drawings updated to reflect current criteria.]

C1.2.9.3. Table AP1-3 is a listing of ECM designs determined to be Undefined structures. A design is placed in this category when it is either known to be structurally weaker than a 7- or 3-Bar ECM design (through a structural assessment, analysis or test), or if insufficient information is available to indicate its strength. When testing is being considered, it should be coordinated through the DDESB to ensure the proper testing is being conducted. [**NOTE:** These designs can be considered for new construction, as approved on a case-by-case basis by the DoD Component, provided they have been thoroughly reviewed and updated to reflect current criteria.]

C1.2.9.4. Table AP1-4 lists magazine (both ECM and aboveground) designs and transportation containers that have reduced QD and/or reduced MCE.

C1.2.10. Appendix AP2, Operation Field Storage, provides information to assist those users who have a need to establish AE storage sites while deployed. AP2 addresses the use of protective construction for the reduction of an MCE. This is important because personnel in the field typically have insufficient real estate available to them to apply default explosives safety quantity distance criteria of reference 1-1. The information contained in AP2 was extracted and consolidated from TP15 and other sources, as necessary. [**NOTE:** A reduced MCE will generally, but not always, result in reduced QD.]

C1.3. **TP 15 SUPPORT DOCUMENTATION**.

C1.3.1. A great deal of supporting documentation (e.g., construction drawings, approval memorandums, DoD Component letters, messages, technical reports, analyses) has been accumulated in the process of developing TP15. Much of the older paper format data has been converted into an electronic format to make it more shareable.

C1.3.2. In conjunction with the above and to complement TP15, the Naval Facilities Engineering Command (NAVFAC) has established a webpage in their Whole Building Design Guide website, specifically devoted to ammunition and explosives storage magazines. The purpose of this webpage is to assist in the planning and/or design of new Ammunition and Explosive (AE) storage magazines for the Department of Defense (DoD) by providing definitions, descriptions, requirements, and standards of drawings and specifications as available. The information, which is intended to offer a general introduction into the design and approval of AE storage magazines, can be found at:

http://www.wbdg.org/design/ammo_magazines.php

and makes specific information (e.g., drawings, approval memorandum, specifications) related to magazine designs shown in Tables AP1-1, AP1-2, and AP1-4 more easily accessible to users. NAVFAC works closely with the DDESB to ensure their web site content is consistent with TP15.

C1.3.3. Finding drawings for older magazines is not an easy process, and in many cases the drawings may no longer be available. Users of this document need to be aware that the organizations referred to as "Designer" reflect the original designer; therefore, in some cases, the listed design organization may no longer be in existence. In such cases, the location of their drawings may not be known. Drawings for newer magazines, or information pertaining to design drawings, may be obtained from the design and explosives safety agencies shown below:

**Army** U.S. Army Corps of Engineers

| | |
|---|---|
| | Engineering and Support Center, Huntsville (USAESCH)<br>Attn: CEHNC-ED-CS-S<br>P.O. Box 1600<br>Huntsville, AL 35807-4301 |
| | Defense Ammunition Center<br>Attn: SJMAC-EST<br>1 C Tree Road<br>McAlester, OK 74501-9053 |
| **Navy** | Naval Facilities Engineering Command (NAVFACENGCOM)<br>Attn: NAVFAC Criteria Office (Code 15C)<br>1510 Gilbert Street<br>Norfolk, VA 23511-2699 |
| | Naval Ordnance and Security Activity (NOSSA)<br>Attn: N54<br>23 Strauss Avenue, Bldg D323<br>Indian Head, MD 20640-5035 |
| | Naval Facilities Engineering Service Center (NFESC)<br>Attn: ESC62<br>1100 23rd Avenue, Building 1100<br>Port Hueneme, CA 93043-4370 |
| **Marine Corps** | Commander, Marine Corps Systems Command<br>Attn: AM-EES<br>2200 Lester Street<br>Quantico, VA 22134-5010 |
| **Air Force** | Air Force Safety Center (AFSC)<br>Attn: AFSC/SEW<br>9750 Avenue G, Suite 264<br>Kirtland AFB, NM 87117-5670 |
| **DDESB** | Department of Defense Explosives Safety Board<br>Room 856C, Hoffman Building I<br>Attn: PD<br>2461 Eisenhower Avenue<br>Alexandria, VA 22331-0600 |

C1.4. **KEEPING TP 15 CURRENT**. For TP15 to be of continuing value to all users, it is important that it be kept current and accurate. The DDESB will maintain this document on its Web site [http://www.ddesb.pentagon.mil] and will update it as new protective construction designs are approved and as information is received/evaluated. The explosives safety community is asked to provide the DDESB (Attn: Mr. Eric Deschambault, Code DDESB-PD) with copies of any documentation that can be used to correct, update, or enhance this document. In particular, it is requested that copies of old drawings and electronic photographs be provided for those structures and barricades listed herein (or not listed so that they can be added), for inclusion into the documentation database. Upon receipt, all information will be reviewed, and if warranted, added to TP 15. As new designs are approved or modified, they will be added to the documentation database. In order to improve the timeliness of the magazine listings in TP15, the four tables containing the magazine listings were re-located (as part of TP15 Version 2.0) from Chapter 4 (TP 15, Version 1.0) to Appendix AP1 so that they can be updated periodically without the re-issuance of TP15.

## C1.5. <u>**PROTECTIVE CONSTRUCTION SUBMITTALS TO THE DDESB**</u>.

C1.5.1. In order to clarify requirements for protective construction that are submitted as part of explosives safety site approval requests, the DDESB issued a Memorandum dated 21 October 2009, Subject: “Minimum Requirements to Validate Explosives Safety Protective Construction”. An explosives safety submission is required to validate compliance with reference 1-1 for protective construction: When minimum default separation distances are not satisfied, protective construction may be used in buildings and structures to provide protection against the propagation of explosions, damage to facilities, and loss of life. Accordingly, protective construction may be designed to:

(1 ) Achieve personnel protection,

(2) Protect facilities and equipment, or

(3) Prevent propagation of explosives.

C1.5.2. Reference 1-1, paragraph C4.1, specifically references the Joint Departments of the Army, the Navy, and the Air Force "Structures to Resist the Effects of Accidental Explosions," Army Technical Manual 5-1 300/NAVFAC P-397/AFR 88-22 (TM 5-1300), dated 19 Nov 90, (reference 1-2) for design procedures for the quantitative protection against the propagation of explosions, damage to facilities, and loss of life. This document has been superseded by UFC 03-340-02 (reference 1-3), which has the same title. Therefore, future protective constructions should typically be designed to satisfy the requirements of UFC 03-340-02.

C1.5.3. Of particular importance to Services is that the DDESB memorandum requires documentation from the DoD Component's explosives safety office verifying that the protective construction design/modifications comply with references 1-1 and 1-2 requirements. This verification will be based upon a quality control review (unless a more detailed independent technical review is warranted based upon either the lack of experience by the designer or the use of a new, unvalidated blast analysis or design approach) by a competent DoD blast design agency, such as the Naval Facilities Engineering Services Center (NAVFAC ESC) or the US Army Engineering and Support Center, Huntsville (USAESCH). Because both of these organizations operate on a cost reimbursable basis, projects must arrange payment for these organizations' services.

C1.6. **DEVELOPMENT OF NEW DRAWINGS**. When using a previously approved DDESB protective construction design and site adapting it for construction at a new location, it is strongly recommended that the core structural drawing numbers of the design be captured on the new design drawings. There have been numerous projects where the originally approved design drawing numbers were not captured in a new drawing package, and the pedigree of the design was lost. By default, this situation places the new design into an “unknown” category, and as a result, significant effort/cost has been expended when trying to determine the structural capabilities of a “hardened” design., such as revising the structural strength designation from “Undefined” to 7-Bar for an ECM.

C1.7. **REFERENCES**.

1-1. DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," Under Secretary of Defense for Acquisition, Technology, and Logistics (current edition).
1-2. Joint Departments of the Army, the Navy, and the Air Force "Structures to Resist the Effects of Accidental Explosions," Army Technical Manual 5-1 300/NAVFAC P-397/AFR 88-22 (TM 5-1300), dated 19 Nov 90
1-3. Unified Facilities Code (UFC) 03-340-02, “Structures to Resist the Effects of Accidental Explosions," 5 December 2008

# C2. **CHAPTER 2**

## **MAGAZINE HISTORY**

C2.1. **EARLY HISTORY OF EXPLOSIVES SAFETY DISTANCES**. Throughout this document, reference is made to the American Table of Distances (ATD). The following provides a brief history of the ATD, its origins, and how it was initially used by the military services. The historical information contained in this section was extracted from references 2-1 and 2-2 and various Board records between 1928 and 1956. Reference 2-3 provides a listing and summary discussion for the meetings that were held during this time period.

C2.1.1. Prior to 1910, there was no recognized rule or table that specified safe distances from AE storage sites in the United States. Because of this, large quantities of AE could be and were stored in close proximity to population centers, often leading to disastrous results when accidents occurred. In 1910, a group associated with the explosives industry developed the ATD, with an objective of establishing distances between stores of explosives and its surroundings. The goal was to minimize hazards to the public and to public property. The ATD distances were based on experiences from over 100 notable explosions involving up to 800,000 pounds net explosive weight (NEW). Following development of the ATD, a number of states incorporated it into their laws. The ATD was adopted for use by the military services in 1928. The circumstances leading to military adoption of the ATD are described in C2.1.3 below.

C2.1.2. There were two elements of the ATD that eventually led to its demise as the continued basis for military safe distances for the storage of high explosives. The first was that it was based on late nineteenth and early twentieth century accidents and did not include more “recent” (in 1945) accidents involving more energetic or powerful military explosives. The second was that the primary basis for the ATD was the assumption the explosion took place in the open, behind a shield or barricade. On this basis, the ATD permitted the use of reduced distances, if the explosion site was barricaded. However, by 1945, it was generally recognized that, except in very special circumstances, barricades around explosives had no effect in reducing the maximum distance at which structural damage occurred. This recognition was based on a further assessment of post-1910 accidents involving military explosives and the results of testing that proved that the distances prescribed in the ATD were inadequate in providing an acceptable level of protection to the public involving military explosives.

C2.1.3. The following chronology describes the origin and use of explosives safety distances by the U.S. military, up to 1956, when DoD criteria were first published for the storage and handling of mass-detonating materials:

> ***10 July 1926*** - A catastrophic explosion, ignited by a lightning strike to an explosives storage site, occurred at Lake Denmark Naval Ammunition Depot, NJ (located adjacent to Picatinny Arsenal and approximately 3-1/2 miles from Dover, N.J). The initial event propagated to additional explosives storage sites. This accident virtually destroyed the depot, causing heavy damage to adjacent Picatinny Arsenal and the surrounding communities, killing 21 people, and seriously injuring 51 others. The monetary loss to the Navy alone was $46 million (1926 dollars). Injuries occurred out to a distance of three

miles. Window breakage extended out to a distance of 5 miles. This event caused widespread concern and indignation among the public about the practice of building arsenals and storing dangerous explosives near populous communities.

***1927*** - In light of the Lake Denmark disaster and the general public's concern with military ammunition storage, the 70th Congress directed that the Secretaries of War and Navy prepare a report on the subject of ammunition storage conditions. The Secretaries subsequently assigned a Joint Board on Ammunition (JBA), consisting of four military officers, "to conduct a survey of points of supplies of ammunition and components thereof for use of the Army and Navy...". This Board convened on 9 Jan 1928. In their final report, submitted approximately two months later to the Secretaries, the Board made specific recommendations for correcting the storage problems they found; they also recommended the adoption of the New Jersey explosives law, which had incorporated the ATD as its standard of safety. The Secretaries approved the Board's report.

***1928*** - The Secretaries transmitted their final report on 9 Mar 1928 to the House of Representatives. The Committee on Appropriations printed the report and it became known as House Document No. 199. Subsequently, a special sub-committee of the House of Representatives was appointed to investigate the issue of explosives storage. During the hearings, the sub-committee chairman suggested that a permanent board of munitions storage, representing both the Army and Navy, be established. The sub-committee also recommended appropriations to carry out the recommendations of House Document 199. Congress approved both the recommendations and the appropriations. Subsequently, the Joint Army Navy Munitions Board (JANMB) was established on 6 August 1928. This Board used the ATD as its guide for the application of safe separation distances.

***1945*** - Reference 2-1 was published. This paper compared accident data (117 events from 1882 to 1909) used to develop the ATD to additional accident data (66 events from 1910 to 1945) that had occurred after the ATD was published. The data presented showed that the safety distances required by the ATD were inadequate for military explosives, and that an increase in the safety distances was warranted.

***1948*** - In a 19 Jan 1948 letter, the Army Navy Explosives Safety Board (ANESB) documented their concern that the barricaded inhabited building distance (IBD) and public traffic route distance (PTRD) criteria of the ATD did not provide reasonable and practical protection against loss of life, serious injury, and undue property damage. The ANESB recommended that greater barricaded IBD and PTR quantity distance (QD) be used in place of the ATD. This recommendation was a result of a reappraisal (reference 2-4) of the ATD performed by Dr. Ralph Ilsley of the ANESB and that was published in 1948.

***1948*** - In a 1 Nov 1948 letter, the Armed Services Explosives Safety Board (ASESB) proposed revised QD for mass detonating explosives and ammunition, for adoption by the Armed Services. No formal adoption of these rules was ever accomplished.

***1950*** - In a 1 April 1950 letter, the ASESB again proposed new QD criteria for mass-detonating materials,

***1956*** - DoD Directive 4145.17, QD Standards for Manufacturing, Handling, and Storage of Mass-Detonating Explosives and Ammunition, was published on 7 Dec 1956.

C2.2. **MAGAZINE DESIGN EVOLUTION FROM PRE-1928 THROUGH 1970**. The historical information provided in paragraph C2.2 below was extracted primarily from a December 1950 document (author unknown), and has, except for minor editing changes, been repeated verbatim. It chronicles the evolution of AE magazines from aboveground structures (sometimes barricaded) to the more modern earth-covered structures in existence today. The 1950 document also provides a unique insight into the thought process that drove this evolution. Testing to prove out the theories about QD associated with earth-covered magazines and their structural strengths did not begin in earnest until about 1945. The knowledge gained from this testing was responsible for future magazine designs and separation distance criteria. Testing also disproved many magazine designs that were considered standards for many years; and consequently they became unsatisfactory and obsolete. Paragraph C2.3 documents the testing that has had a significant impact on magazine design and magazine siting criteria.

C2.2.1. **Magazines: PRE-1928**. AE storage facilities were typically of three types. These were aboveground, casemate, and dumps. There was also one other design that was just starting to be constructed in the late 1920s. During the 129th Meeting of the ASESB on 13 May 1953, a discussion was held regarding the Lake Denmark accident of 1926 and the Navy-developed earth-covered magazine design that withstood nearby major explosions of surrounding facilities. At this meeting, the Navy representative to the Board stated the survival of this particular magazine design at Lake Denmark was what started the Navy's move towards construction of earth-covered igloos. This event also later sparked the Army's interest in the earth-covered magazine design concepts.

C2.2.1.1. Aboveground magazines were rectangular, gable-roofed or flat-roofed buildings constructed of masonry (typically tile), corrugated asbestos on a wood frame, or ordinary wood frame construction, with floors at grade or at car-floor level [**Note**: Refers to the presence of a loading dock at railcar floor level]. Occasionally, separate barricades were erected around the magazines, so that safety distances could be halved as permitted at that time by the ATD.

C2.2.1.2. Casemate magazines were masonry vaults in fortifications (sometimes in hills, etc.) and were used only at line stations, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.1.3. Dumps were stacks in the open. This type of AE storage was seldom used, except in wartime.

C2.2.1.4. The Navy's new earth-covered magazine design was constructed of either stone masonry walls or of reinforced concrete and had 1-foot of earth-cover over the top of the structure. The principle behind development of this design was that the structure itself was designed to be weak; in order to avoid confinement and minimize the effects of an internal explosion, but it would be strong enough to protect its contents from fire, wind pressure, snow loads, and other external forces. The purpose of the earth cover was to provide greater protection against long-range missiles that might drop onto the top of the structure.

C2.2.2. **Magazines: 1928 - 1940**. During this time period, there were two major efforts to construct ammunition storage structures and ammunition storage depots. The first followed the 1926 Lake Denmark accident and continued until approximately 1934. This effort was in response to recommendations made by the JBA in their final report to the Secretaries of War and Navy, which then went to the 70th Congress. In their report, the JBA adopted the ATD for the establishment of safe separation distances and made a number of recommendations for constructing new storage areas and relocating ammunition to safer storage sites. The impact of adopting the ATD was that a number of ammunition storage locations, in use at the time, were not able to meet ATD safe separation distance criteria. In order to bring the storage into compliance with the recommendations that were made by the JBA, Congress appropriated funds to construct new magazines at certain existing installations, to construct new depots, and to relocate ammunition, as necessary. These efforts were coordinated, reviewed, and approved by the Joint Army Navy Munitions Board (JANMB), which was formed after the JBA completed their report. As part of this re-stowage effort, new magazines were constructed at Ft. Bragg, Savanna Ordnance Depot, Benecia Ordnance Depot, Delaware Ordnance Depot, Ogden Ordnance Depot, and Aberdeen Proving Ground. Navy installations that gained new magazines were: Navy Mine Depot - Yorktown, VA; Naval Ammunition Depot (NAD) St. Juliens Creek, VA; NAD Hingham, Mass.; NAD Iona Island, NY; NAD Lake Denmark; NAD Mare Island, CA; Naval Torpedo Station, Keyport, WA. New depots were also constructed at Hawthorne, Nevada and Kuahua, HI, in the Lualualei District. The second major ammunition storage (expansion) effort began in the early 1940's as a result of WWII. This effort constructed thirteen (13) new Army Ordnance Depots (see C2.2.3. below) and four (4) new NAD (Burns City, IN; Charleston, SC; Fallbrook, CA; New Orleans, LA).

C2.2.2.1. Aboveground magazines continued to be regarded as the standard and to be constructed. Casemate magazines tended towards obsolescence with the decline in importance of harbor defenses.

C2.2.2.2. The mounded concrete arch magazine was originally designated "under ground magazine" and was soon dubbed the "igloo-type magazine" or simply "igloo". This design appears to have been developed during the 1920s, possibly independently, in different places. The German "Munitionshaus" being constructed in 1938, and probably before, was of this type. U.S. Naval ammunition depots had igloos in existence by 1928. Brigadier General Hof of the Ordnance Department, U. S. Army, learned of the Navy igloos, and in light of their survival at Lake Denmark, directed adoption of this concept by the Army. [**Note**: General Hof was one of four military officers assigned to the 1928 Joint Board on Ammunition that reviewed ammunition storage following the Lake Denmark accident. He was also the first Chairman of the JANMB.]

C2.2.2.3. These igloos consisted of a reinforced concrete, approximately semi-circular barrel arch springing from a floor at grade (or occasionally at car-floor level). It was thus above natural grade, but was called "underground", because the arch and rear wall were covered over with earth.

C2.2.2.4. Factors that led to the preference for the "underground" magazine over the older aboveground types were:

C2.2.2.4.1. The thermal insulation qualities of the concrete and earth would eliminate the extreme high temperatures which were experienced in aboveground magazines and which accelerated the deterioration of smokeless powder and other stores.

C2.2.2.4.2. The earth-cover would facilitate camouflage.

C2.2.2.4.3. It was expected that the igloo would be less of a hazard to its environs than an aboveground magazine, particularly an unbarricaded, aboveground magazine. It was supposed that an explosion of the igloo's contents would be confined by the thick haunches of the concrete arch and by the thick earth fill at the sides, and would be vented upwards through the thin crown. It was expected that the radius of simultaneous ("sympathetic") detonation, the radius of structural damage, and the range of debris would all be reduced.

C2.2.2.4.4. In view of C2.2.2.4.3 above, intermagazine distances, inhabited building distances, etc., could be halved because of being "barricaded" without the necessity for separate barricades, and land area requirements would be substantially reduced.

C2.2.2.4.5. It was supposed that the igloo would be missile-proof and resistant to structural damage, with respect to an explosion at an adjacent igloo. In aboveground magazines, even though barricaded, explosives subject to initiation by missiles or by structural damage had to be separated from missile-forming and mass-detonating ammunition by inhabited building distance, rather than by intermagazine separation distance. With igloos, this requirement could be waived, with a further saving in land requirements, to provide increased flexibility and efficiency in space utilization.

C2.2.2.4.6. The possibility of propagation of an explosion from magazine to magazine would be reduced to practically zero.

C2.2.2.5. **First Army "Standard" Magazine ("old Savanna type")**.

C2.2.2.5.1. OQMG Drawings 6379-160 and 6379-161; changed to 652-311 and 652-312 (Ordnance Drawings. 19-2-03 and 19-2-04, Magazine Type 30), dated 19 July 1928. "Standard Underground Magazine".

C2.2.2.5.2. This reinforced concrete (RC) magazine had interior dimensions of 25 feet wide, 40 feet 4 inches long, and 10 feet high at the crown. The arch crown was 5 inches thick. The base of the arch was 10 inches thick. The front concrete wall had a thickness of 4 inches and the rear concrete wall was 6 inches thick. The arch and walls had wire mesh reinforcement that was electrically grounded. The magazine had a six-foot by eight-foot double steel-clad wood door. A full-timber headwall was provided. There was no platform or apron, and the magazine fronted directly onto the road. An optional front barricade, across the road, could be constructed. Vent louvers were provided. Earth cover, at the crown, was one-foot thick. [**Note**: The term "headwall" is now used to describe a magazine's front wall, and the term "wingwall" describes the wall (located on both sides of the headwall) that supports a magazine's earth cover. In the early years of earth-covered magazine design, the term "front wall" denoted just the portion that fronted the magazine, with the "headwall" defining the portion supporting the magazine's earth cover.]

C2.2.2.5.3. This magazine was constructed at the following military installations: Savanna, Delaware, Benicia, and Aberdeen.

C2.2.2.6. **"Old Line" Type Magazine**.

C2.2.2.6.1. OQMG 652-295 and 652-296 (Ordnance Drawings 19-2-107 and 19-2-108, Magazine Type 42), dated 20 June 1933.

C2.2.2.6.2. Same as C2.2.2.5 above, except an exterior monorail was added, the doors were changed to steel plate, the headwall was changed to concrete, earth cover was increased to two feet thickness, a sand cushion was placed on the magazine's water-proofing, and the concrete front wall's thickness was increased to 6 inches.

C2.2.2.6.3. This magazine was intended for use at line stations, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.2.7. **"Old Depot" Type Magazine**.

C2.2.2.7.1 **Drawings**.

C2.2.2.7.1.1. **Forty-foot length**: OQMG Drawings 652-317 through 652-320 (Ordnance Drawings 19-2-121 through 19-2-124 and 19-2-130, Magazine Type 48), dated 9 December 1935, "Underground Magazine-Igloo Type" (Type 1).

C2.2.2.7.1.2. **Sixty-foot length**: OQMG Drawings 652-326 through 652-331 (Ordnance Drawings 19-2-125 through 19-2-129, Magazine Type 49), dated 23 July 1937. This magazine had an interior width of 26 feet 6 inches and an interior height of 12 feet 9 inches. A monorail was provided that was supported by pilasters projecting from the end walls. It had a single 4-foot wide door. Arch wire mesh was used for arch reinforcement. The crown thickness was 6 inches and the reinforced concrete front wall thickness was 7 inches.

C2.2.2.7.1.3. These types of magazine were constructed at "old ordnance depots" (Raritan and Benecia Arsenal, Charleston, Curtis Bay, Delaware, Nansemond, Ogden, San Antonio, Savanna, and Wingate) and at line stations, such as Coast Artillery and Harbor Defense installations and seacoast battery emplacements. During construction at Ogden, the headwalls were stubbed (shortened) by the elimination of wingwalls.

C2.2.2.8. **Earliest Known Steel Arch Magazine**. The below information and photographs of an early1940-era, all steel magazine located at Camp Blanding, FL, was provided courtesy of an architectural historian doing research on the installation. He contacted the DDESB as part of his research into 24 similar magazines he was evaluating. “Stamped” on one panel for each of the head wall plates is "Order 3171, Oalvert Iron Wks, Atlanta, Ga". The rip rap walls were added in 1985. Graffiti from the 1940s is written on the majority of the igloos. The earliest is dated April 9, 1940 and the next closest is February 24, 1941, with the majority dated from 1943. Based on his research, assuming the 1940 date is correct, then these igloos were built for the Florida Army National Guard (FLARNG), prior to the U.S. Army taking over Camp Blanding. The Camp historian thought the 1940 date was a little suspect. He was not aware of the FLARNG building the ASP, but believed that the Army did it when the federal government took over Camp Blanding on September 14, 1940. The following photographs show an exterior and interior view:

C2.2.3. **<u>1940 - 1945.</u>**

C2.2.3.1. **<u>"New Depots" Type Magazine.</u>**

C2.2.3.1.1. OQMG Drawings 652-340 through 652-349, dated 27 September 1940. The drawings were lost and replaced by OQMG Drawings 652-377 through 652-386, dated 30 October 1940. Reference is made in the original documentation to this being a Type 2 magazine. Reinforced concrete headwalls were 7 inches thick and the crown was 6 inches thick.

C2.2.3.1.2. This design provided for three optional interior lengths (40-foot 4 inches (1,003 square feet), 60-foot 8 inches (1,528 square feet), or 81-foot 0 inches (2,147 square feet)), deleted the monorail and pilasters, and deleted vents, which were subsequently restored by Revision C, dated 1941).

C2.2.3.1.3. This type magazine was constructed at the following new Ordnance Depots: Anniston, AL; Milan, TN; San Jacinto, TX; Portage, OH; Red River, TX; Seneca, NY; Navajo, AZ; Black Hills, SD; Blue Grass, KY; Sierra, CA; Pueblo, CO; Letterkenny, PN; and Umatilla, OR.

C2.2.3.2. **"World War II" Type Magazine.**

C2.2.3.2.1. OCE Drawings 652-686 through 652-693, dated 27 December 1941, "Underground Magazine-Igloo Type". Magazine Type O. Revised 14 March 1942. This design was available in 60 and 80-foot lengths.

C2.2.3.2.2. This design has fully reinforced arch and walls and a full concrete headwall, vents were restored, an alternate concrete door was added, the front wall thickness was increased to 10 inches, and sand fill was deleted.

C2.2.3.2.3. This type magazine was constructed at Army Ordnance Depots and at line stations. [**Note**: A 2 December 1944 document lists this magazine type being constructed at the following depots in 1941 and 1942: Umatilla (652 - 60'; 358 - 80'), Wingate (550 - 60'; 100 - 80'), Anniston (200 - 60'; 600 - 80'), Portage (354 - 60'; 100 - 80'), Milan (600 - 60'; 100 - 80'), San Jacinto (146 - 60'; 54 - 80'), Seneca (400 - 60'; 100 - 80'), Red River (300 - 60'; 400 - 80'), Letterkenny (200 - 60'; 600 - 80'), and Sierra (200 - 60'; 600 - 80').]

C2.2.3.3. **"Huntsville" Type Magazine.**

C2.2.3.3.1. OCE Drawings 652-1012 through 652-1014, dated 29 April 1942. Magazine Type A-O. This design was available in 40, 60, and 80-foot lengths.

C2.2.3.3.2. This magazine was a redesign of the World War II Type Magazine with the goal being to conserve critical materials needed for the war effort. Reinforcing was reduced, with the reinforcing bars replaced by 4" by 4" wire mesh weighing 62 $lbs/ft^2$ in the extrados (exterior surface of the arch) only; the headwall was stubbed (earth fill spilled around front corners); the door was changed to 6-foot double sheet steel; and the front wall thickness was reduced to 8 inches.

C2.2.3.3.3. This magazine type was constructed at Ordnance Department industrial installations [**Notes**: An Ordnance Department industrial installation was an activity operated by the Ordnance Department for the production of ammunition. A 2 December 1944 document states that 40, 60, and 80-foot magazines were constructed at the following depots in 1942: Pueblo (200 - 60', 600 - 80'), Black Hills (200 - 60', 600 - 80'), Blue Grass (200 - 60', 600 - 80'), Navajo (200 - 60', 600 - 80'), and Tooele (200 - 60', 600 - 80'). Two forty-foot magazines were constructed at each of the following ordnance depots: Umatilla, Wingate, Anniston, Portage, Milan, San Jacinto, Seneca, Red River, Letterkenny, Pueblo, Black Hills, Blue Grass, Navajo, and Tooele]

C2.2.3.4. **"Corbetta and Beehive" Type Magazines.** This has also been called a "Dome-Type" Magazine.

C2.2.3.4.1. OCE Drawings 652-1000 through 652-1010, dated 19 February and 23 March 1942, "Underground Magazines 52-foot 0 inches and 44-foot seven inches, Corbetta and Beehive Types".

C2.2.3.4.2. This design has a reinforced concrete dome (oblate hemispheriod) and the floor is at grade level. Other features include 2-feet of earth cover, a single 6-foot double sheet-steel door, and a buried counter-poise (ground loop), to which was grounded the magazine's metallic masses (reinforcing steel, door, ventilator). The ventilator also had an air terminal for lightning protection.

C2.2.3.4.3. This type magazine was constructed at Curtis Bay (location for pilot model magazine), Sioux (A 2 December 1944 document lists the following quantities as being constructed 202 - Corbetta; 600 - Beehive), Susquehanna, and Ordnance Department industrial installations.

C2.2.3.5. **"Richmond" Type Magazine.**

C2.2.3.5.1. OCE Drawing 652-1017 and 652-1018, dated 13 May 1942.

C2.2.3.5.2. This magazine is not an igloo, but it has been frequently so miscalled. It has massive masonry side and rear walls, which are banked with earth. It has a wood frame front wall, with asbestos shingles, and a wood frame gable roof.

C2.2.3.5.3. This type magazine was constructed at Ordnance Department industrial installations.

C2.2.4. **1945 Through 1970s.**

C2.2.4.1. The following door design/installation drawings and sketches were provided to the Armed Services Explosives Safety Board (ASESB) for review. Prints were furnished to OCE along with ASESB recommendations for their use in lieu of the typical four-foot, single blast-proof door being used at the time.

C2.2.4.1.1. Office of the Chief of Ordnance (OCO) Sketch UD-29, dated 11 February 1946 (revised 14 March 1946), was for a 6-foot double blast-proof door.

C2.2.4.1.2. OCO Sketch UD-29A dated 14 Mar 1946, for installation of Sketch UD-29 6-foot double blast-proof door on existing igloos.

C2.2.4.1.3. FP 3a, dated 23 April 1946, for a double blast-proof door, was designed by Mr. Stradley of Code ORDFT, for special projects at Ordnance Depot Wingate.

C2.2.4.2. **"Engineer" Type Magazine**.

C2.2.4.2.1. OCE Drawing 33-15-01 (7 sheets), dated 27 January 1948.

C2.2.4.2.2. This magazine design was similar to the World War II Type, except that door was changed to an un-reinforced 6-foot single, steel plate; the headwall was stubbed; the platform and apron were rearranged; the front wall was restored to a 10-inch thickness; full reinforcement was restored; and sand fill was restored.

C2.2.4.2.3. This design was issued primarily for line station use, such as Coast Artillery and Harbor Defense installations, posts, and seacoast battery emplacements.

C2.2.4.3. **Observed Magazine Design Problems**.

C2.2.4.3.1. The door of the "Engineer" Type Magazine was questioned as to its blast resistance capability.

C2.2.4.3.2. The "Corbetta and Beehive" Type Magazines, originally approved by OCO, were considered unsatisfactory following their approval and were officially made obsolete.

C2.2.4.3.3. The "Huntsville" Type Magazine had never been approved and was considered unsatisfactory.

C2.2.4.3.4. The "Richmond" Type Magazine, a wartime substitute, was never classed as an igloo magazine for QD purposes.

C2.2.4.3.5. All pre-World War II Magazines were no longer considered fully satisfactory with respect to explosives safety.

C2.2.4.4. **Correction of Design Problems**. In 1945, preliminary magazine testing had begun with the goal of proving out magazine designs and the separation distances being used by the Services. As a result of the data obtained from this preliminary testing, the ASESB issued a report, dated 1 April 1950, that called for the front walls of magazines to be increased in strength. This report also recommended that doors be widened to provide for safer handling of AE. On February 26, 1951, the Air Force concurred with criteria for a revised magazine design and Drawing DEF-E-33-15-04, Magazine, Mounded Concrete Igloo, Type MA-5, dated 29 May 1951 was created. With this design, magazine designs evolved from those based on theory to magazine designs founded on test results.

C.2.2.4.5. **New Army Magazine**.

C2.2.4.5.1. OCE Drawing 33-15-06 (6 sheets), dated 1 August 1951.

C2.2.4.5.2. This magazine represented a redesign of Drawing 652-686 through 652-692: The headwall thickness was increased to 12 inches; larger diameter and more reinforcing was used; and the door design was changed to two 4-foot wide doors that were 4-inches thick and were provided with vertical stiffeners.

C2.2.4.6. **Steel Arch Magazine**.

C2.2.4.6.1. In 1963, three semi-circular, corrugated steel-arch magazines with hinged double-leaf, steel plate doors were developed by Black and Veatch for the Air Force and the Defense Atomic Support Agency (DASA). (**Note:** It appears that both of these drawings were each a corrugated steel magazine design that had a 12-inch thick reinforced concrete headwall, a corrugated steel arch, and a reinforced concrete rear wall. A flow-through design also was developed which had two headwalls and no rear wall). Access to the magazine was provided via a hinged double-leaf steel plate door. A minimum of 2 feet earth-cover was specified. These magazines were:

C2.2.4.6.1.1. AW 33-15-63 (Air Force), dated 5 Mar 1963. Two separate designs were identified as part of this drawing: (a) Flow through design consisting of two headwalls and no rear wall. The magazine measured 11 feet wide by 68 feet long, and (b) a magazine design that measured 11 feet wide by 17 feet long. The door opening for both designs measured 10 feet wide by 8 feet high.

C2.2.4.6.1.2. AW 33-15-64 (Air Force), dated 10 May 1963. This design measured 25 feet wide by 60 feet long and had a door opening that measured 10 feet wide by 10 feet high.

C2.2.4.6.1.3. 33-15-65 (DASA), dated 10 Jan 1963. This drawing also had two separate designs identified on it: (a) 7 feet 6 inches by 11 feet long (min) to 27 feet (max), in increments of 2 feet, and (b) 9 feet wide by 11 feet long (min) to 27 feet (max), in increments of 2 feet. Each design had a door opening that measured 6 feet wide by 6 feet 4 inches high.

C2.2.4.6.2. Because these corrugated steel arch designs reflected a major conceptual change to the typical arch design (reinforced concrete) previously tested and upon which criteria were based, it was unknown whether existing magazine separation distance criteria could be applied to the semi-circular corrugated steel arch magazine design. Consequently, a series of tests were initiated at Naval Ordnance Test Station (NOTS), China Lake, CA, between January 1962 and December 1963. The results from the testing, which established minimum criteria for semi-circular, corrugated steel-arch magazines are summarized in C2.3.6.

C2.2.4.6.3. The 3 semi-circular, corrugated steel-arch magazine designs were approved at the 225th ASESB Meeting as Standard designs for 500,000 lbs NEW storage using separation distances determined by the NOTS testing.

C2.2.4.6.4. Subsequently, the door and headwall design was further tested during the Explosive Safety Knowledge IMprovement Operation (ESKIMO) 1 test to evaluate the possibility of further reductions of intermagazine distance and to develop additional information to indicate the minimum safe distance to use between the concrete headwall of a magazine and the earth-covered side and rear walls and barricaded headwall of another magazine. These tests are summarized in C2.3.7. The principal conclusions arrived at from the test were that earth-covered, semi-circular steel-arch magazines, without intervening barricades, could be separated in a face-to-rear orientation by $2.0W^{1/3}$ and in a face-to-side orientation by a distance of $2.75W^{1/3}$. In addition, as a result of ESKIMO I data, the DDESB adjusted the spacing for a face-to-face orientation to $11W^{1/3}$ when unbarricaded, and to $6W^{1/3}$, when barricaded.

C2.2.4.7. **Modification of Steel Arch Thickness.** In response to a Navy query regarding NAVFAC Standard Steel Arch Magazines and an interest by the Navy in moving from a 1 gage corrugated steel arch to an 18 gage corrugated steel arch, ASESB-PP Memorandum of 18 June 1971states that "The ASESB has recommended new standards for separation of earth-covered igloos which provide the same separation distances between earth covered surfaces of standard types regardless of the material of construction. The results of a number of recent tests including the Air Force Big Papa series indicate the volume of earth interposed is more important than other factors in preventing communication of detonation. If the headwall and rear wall construction proposed by the Navy are identical to the standard steel arch magazine, and the arch is of sufficient strength to permanently support the standard earth cover, these may be considered standard for the application of the siting criteria."

C2.2.4.8. **Oval Steel Arch Magazine**.

C2.2.4.8.1. OCE Drawing 33-15-73, dated February 1975.

C2.2.4.8.1. In the period 1972 through 1974, the Office, Chief of Engineers (OCE), contracted for and supervised the design of a new magazine design. The structure was built of a corrugated steel arch having a non-circular (oval) cross section, with a single leaf sliding door mounted on a reinforced concrete headwall. This designed was considered optimal for unitized loads of rectangular shape and its relative construction economy (as compared to an all reinforced-concrete arch and headwall magazine design).

C2.2.4.8.2. Since the design represented a departure from the previously approved semi-circular steel arch design, it was incorporated into a series of tests, known by the acronym ESKIMO, the DDESB was developing and sponsoring to further define magazine separation distance requirements. A full-scale prototype of the oval steel arch magazine was tested at the Naval Weapons Center, China Lake, CA. The tests demonstrated the safety of the oval arch magazine design at the minimum separation distances permitted by QD standards for side-to-side orientations and for certain permissible headwall exposures. In January 1976, the DDESB approved the oval steel arch magazine (specifically OCE 33-15-73) as a Standard magazine for the storage of up to 500,000 lbs NEW at minimum separation distances permitted.

C2.2.4.9. **Design Enhancements/New Designs.** Enhancement of existing designs and development of new designs has been ongoing, and there has been significant testing and data analysis associated with their development. That information has been captured in the next section (C2.3), which provides full descriptions and results of that work. Descriptions and illustrations of those newer designs can be found in Chapter 4.

## C2.3. **MAGAZINE TESTING**.

C2.3.1. **Magazine Siting (From Laws of New Jersey - 1925)**. As discussed at the start of this chapter, the JMB adopted the explosives laws of the State of New Jersey for its standard of safety. These laws, which incorporated the ATD, specified the following with respect to explosives storage:

C2.3.1.1. Magazines in which more than 50 pounds of explosives are kept or stored must be detached from other structures and magazines.

C2.3.1.2. Magazines where more than 5,000 pounds of explosives are kept or stored must be located a minimum of 200 feet from other magazines.

C2.3.1.3. Magazines where quantities of explosives over 25,000 pounds are kept or stored must be located a minimum of 200 feet from other magazines, with an increase of two and two-thirds (2-2/3) feet for each 1,000 pounds of explosives in excess of 25,000 pounds.

C2.3.1.4. "No quantity in excess of 250,000 pounds of explosives ... shall be had, kept, or stored in any factory building, or magazine in this state."

C2.3.2. **Magazine Siting (post 1928)**. In March 1928, this Board established additional AE storage rules to complement the ATD. These rules were:

C2.3.2.1. The Army could store up to 250,000 pounds NEW at a minimum IMD of 400 feet.

C2.3.2.2. The Navy could store up to 143,000 pounds NEW at a minimum IMD of 500 feet.

C2.3.3. **Naval Proving Ground, Arco, Idaho, 1945 Testing**.

C2.3.3.1. During this period of history, the armed services were limited to an allowable quantity per storage unit of 250,000 pounds, which for strategic and economic reasons was regarded as the maximum quantity whose loss could be risked at one time. However, with the close of World War II, on-hand ammunition tonnage quantities were so vast that the earlier considerations were no longer valid and the question of safety of surrounding populations and structures and the avoidance of major losses became the only impediments to raising the limit. It was out of this concern that the JANASB, in October 1944, recommended to the Secretaries of War and Navy, that testing be conducted to determine whether standard intermagazine distance might safely be reduced and whether AE might safely be stored in open stacks midway between existing magazines. Successful testing would help alleviate safety concerns, eliminate the need to purchase additional land for the construction of new magazines to handle the influx of returning

AE, extend available data on QD relations for storage of high explosives, and provide a check on the inhabited building safety distances for barricaded storage, as prescribed by the ATD. The ATD permitted the reduction of inhabited building safety distances by 50%, if a barricade stood between the explosives and the inhabited building. In October 1947, the Secretaries of War and Navy approved testing and each service contributed funding to conduct the tests, which required the construction of four test igloo magazines, three revetments, and a wood-frame barracks test building.

C2.3.3.2. The 1945 tests are documented in reference 2-5. The following conclusions were reached from the tests:

C2.3.3.2.1. The Army standard intermagazine spacing of 400 feet (K6.4), clear distance edge-to-edge, between earth-covered, reinforced concrete, arch-type (igloo) magazines that were limited to 250,000 pounds net pounds of high explosives in each, could be reduced to 185 feet (K2.94), without appreciable risk that a detonation of the entire contents of one such magazine would propagate to another. This 185-foot clear distance results when an additional magazine is built midway between two existing magazines at the Army standard intermagazine spacing of 400 feet.

C2.3.3.2.2. Structural damage done to an igloo when a 250,000-pound charge is detonated in a neighboring igloo at 185-foot (K2.9) clear distance is slight.

C2.3.3.2.3. When 250,000 pounds of high explosives are detonated in an open revetment located midway between igloos 400 feet (K6.4) apart, it is improbable that the explosion will propagate to either igloo, and they will not suffer severe damage.

C2.3.3.2.4. A two-story, wood-frame, standard-type barracks building is not entirely safe from structural damage, and its occupants are likely to suffer severe injury from flying fragments of window glass, when 250,000 pounds NEW of high explosives are detonated within an igloo magazine at a distance of 2,155 feet (K34.2), the safety distance specified by the Table of Distances for inhabited buildings from a barricaded storage of such quantity.

C2.3.3.3. In February 1946, the JANASB voted to continue the test program begun in 1945, with the primary interest in further investigating the possibility of safely increasing the potential storage capacities of existing storage facilities, without acquiring additional land, by raising the allowable explosive limit per igloo magazine to 500,000 net pounds of high explosives. In addition, the Board contemplated that it might be safe and feasible to double the quantity of high explosives per igloo magazine (to 500,000 pounds), while reducing by 50% the required 400-foot intermagazine separation distance used between magazines. In order to evaluate this possibility, the Board chose to use a 185-foot (K2.3) spacing (side-to-side) between test magazines and a 360-foot (K4.5) spacing (front-to-rear) spacing between test magazines. One other area that the Board decided to evaluate was the effect that increased earth-cover might have on the blast phenomena. This would be done using a number of 1/10-scale model igloos, which were already available, and a full-scale igloo magazine remaining from the 1945 test series.

C2.3.4. **<u>Scale Model Testing at Underwater Explosives Research Laboratory, Woods Hole, MA, 1945 Testing, and Naval Proving Ground, Arco, Idaho, 1946 Testing</u>**.

C2.3.4.1. Scale model tests of detonations of high explosive charges in igloo magazines and in open storage were conducted at Naval Proving Ground, Arco as a sequel to similar tests by the Woods Hole Oceanographic Institution, in order to further study the effects of such explosions on next-in-line igloos, to investigate whether the model law holds for determining various phenomena from explosions, and to determine how increased earth cover on the exploding donor magazine affects these phenomena. In order to investigate the effects of explosions in igloos on adjacent igloos, without going to great expense, the Board arranged for tests to be conducted using 1/10 linear scale models of the standard Army and Navy 27-foot by 80-foot igloo magazine and 1/1000 ratio of charge weights. Eight tests were held, six with 250-pound charges and two with 500-pound charges, simulating certain phases of the 1945 and 1946 full-scale test programs.

C2.3.4.1.1. The 1945 Woods Hole scale model testing is recorded in reference 2-6, while the 1945 Arco scale model test report is provided by reference 2-7. The following conclusions were reached from the this series of tests:

C2.3.4.1.1.1. The model law holds for air blast, crater diameters, horizontal earth movement, and damage to structures by air blast.

C2.3.4.1.1.2. The model law does not hold for crater depths, vertical ground movement, vertical component of ground shock, or damage to target igloos (which is partially caused by ground shock).

C2.3.4.1.1.3. Increased earth cover on a donor igloo magazine reduces air blast and damage to target structures.

C2.3.4.1.1.4. Use of standard service igloos does not justify halving the distances, specified by the ATD, for safety of inhabited buildings from unbarricaded charges. The ATD permitted halving required distances, if a barricade was present. [**Note**: Use of the term "standard" in 1945 and 1946, to describe an igloo, merely indicated that it was typical of what was being constructed by the Services at the time. During this period of magazine design history, the explosives safety community was still trying to determine what the strengths of these magazine designs were and what role these strengths played in preventing propagation. It was a result of these early tests that the term "standard" was revised to describe a magazine that, because of its inherent strength, met specific construction criteria that would permit it to be located closer to adjacent magazines containing up to 500,000 pounds NEW, as compared to those magazine designs that did not meet the more robust construction criteria.]

C2.3.4.1.1.5. Standard Army revetments around open charges do not reduce air blast generated by detonation of their contents.

2.3.5. **Full-Scale Reinforced Concrete, Arch-Type Igloo and Revetment Tests at Naval Proving Ground, Arco, Idaho, 1946**.

C2.3.5.1. **Test Description**. This series of tests was the continuation of testing begun in 1945, as described in paragraph C2.3.3, above. One of the proposed tests would utilize the remaining full-scale igloo from the 1945 test series, in order to obtain further data on the effects of augmented earth cover on a donor igloo with respect to blast damage and window breakage in nearby habitation-type buildings. The new facilities constructed in support of the 1946 testing included two reinforced concrete arch, earth-covered igloo magazines, two revetments, and three modified barracks structures. One of the igloos was constructed to Army Drawings (OCE) 652-687 through 652-693, while the second igloo was constructed to Bureau of Yards and Docks Drawings 357428 through 357430, except an Army-type door was installed. The Army igloo had no barricade, while the Navy igloo was provided a front barricade. These two igloos were tested with 500,000 pounds NEW of high explosives. The igloo used for the increased earth cover test was also of the Army design (Drawings 652-687 through 652-693) and its earth-cover at the crown was increased to a depth of approximately 6-1/2 feet. This igloo was tested with 250,000 pounds NEW of high explosives. The revetments were of the standard Army-type in use at the time.

C2.3.5.2. **Test Conclusions**. The report for this series of tests is provided by reference 2-8. The following conclusions were reached from these tests:

C2.3.5.2.1. Clear distances between standard reinforced concrete, arch-type igloos could be reduced to 185 feet (side-to-side), which equates to $2.3W^{1/3}$, for 500,000 pounds NEW.

C2.3.5.2.2. The maximum quantity of high explosives permitted in each igloo tested could safely be raised to 500,000 net pounds of high explosives.

C2.3.5.2.3. Army magazine design (OCE) 652-687 through 652-693 and Bureau of Yards and Docks (Bureau Y&D) magazine design 357428 through 357430, modified with an Army blast door, were qualified as standard magazines for 500,000 pounds of high explosives.

C2.3.5.2.4. Based on the damage experienced by the barracks structures from an explosion involving 500,000 pounds of high explosives, the 50% reduction of inhabited building distances, as permitted by the ATD when there is a barricade between the explosives and the inhabited buildings, is unwarranted in the case of standard earth-covered magazines. Testing showed that only a 20% reduction of the unbarricaded inhabited building distance is warranted.

C2.3.5.2.5. No evidence was produced to support the theory that an increase in earth-cover was sufficient to warrant reduction in inhabited building distances.

C2.3.5.3. **Criteria Change as a Result of Testing**. Based on the results of this testing, Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, and other magazines of equivalent strength, were required to use a side-to-side magazine separation distance of 210 feet (K3.3) for quantities up to 250,000 net pounds of high explosives and a magazine separation distance of 400 feet (K6.3 to K5.0) for quantities over 250,000 pounds and up to 500,000 pounds. When modified by the addition of an Army blast door, these magazines were permitted to store up to 500,000 pounds with a side-to-side intermagazine separation distance of 185 feet (K2.3). [**Note**: There is a 9-year gap between when the above testing of Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430 occurred (1946) and when the Bureau Y & D blast door design, Drawing 626739, dated 19 March 1954, was published. The 1955 ASESB explosives safety standard specified that, in order to qualify as a "standard" magazine, Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, was required to be modified in accordance with Bureau Y&D Drawing 626739, dated 19 March 1954. Between the years 1946 and 1954 Bureau Yards & Docks' (Y&D) magazine design 357428 through 357430, dated 9 August 1944, was considered as a "standard" magazine when it had been modified with an Army blast door. It is therefore concluded that if the blast door being used on an arch-type igloo was equivalent to that being used with approved Army magazine design (OCE) 652-687 through 652-693, then it qualified the igloo to be considered a "standard" magazine.]

C2.3.6. **Earth-Covered, Steel-Arch Magazine Tests, Naval Ordnance Test Station (NOTS), China Lake, CA, 1962 -1963**.

C2.3.6.1. **Test Description**. Full-scale and model testing experiments conducted previously had demonstrated that the historical criteria for the storage of high explosives could be substantially improved for standard, reinforced-concrete, arch-type igloo magazines. The series of tests conducted between January 1962 and December 1963, at NOTS, had three goals; 1) determine the feasibility of reducing the land area required for high explosives storage by further reducing intermagazine spacing, 2) establish the minimum safe distance permissible between earth-covered, steel-arch magazines, and 3) compare the intermagazine protection afforded by the more economical steel-arch magazine with that afforded by the reinforced concrete, arch-type magazine. The steel-arch-type magazine designs to be tested were the Air Force's 33-15-63 and 33-15-64.

C2.3.6.2. **Test Conclusion**. The test series are documented in reference 2-9. The test concluded that steel arch magazine igloos could be safely located at side-to-side separation distance of K1.25; rear-to-rear separation distance of K1.5, and rear-to-front (unbarricaded) of K4.5.

C2.3.6.3. **Criteria Change as a Result of Testing**. Based on the results of this test series, the 225th ASESB of 19 February 1964 approved the siting of earth-covered, steel-arch magazines, constructed per Drawings AW 33-15-63 (5 March 1963), AW 33-15-64 (10 May 1963), and 33-15-65 (10 January 1963), or their equivalent, as standard magazines, using the following criteria:

* Spacing is to be $1.25W^{1/3}$ for side-to-side and side-to-rear orientations.
* Spacing is to be $1.5W^{1/3}$ for a rear-to-rear orientation.
* Spacing is to be $4.5W^{1/3}$ for front-to-rear or front-to-side orientations.

* No magazine shall be spaced one from another at less than 7 feet.

C2.3.7. **Explosive Safety Knowledge IMprovement Operation (ESKIMO) test series (I through VII), Naval Weapons Center, China Lake, CA., 1971 through 1985**. Testing prior to the ESKIMO Series confirmed that some selected arch-type magazines, extant at that time, could be sited side-to-side at a scaled distance of $1.25W^{1/3}$, and that the separation distances for other orientations were overly safety conservative. Since these earlier tests did not satisfactorily answer questions about necessary separation distances for other orientations, additional testing was necessary. These questions led to the development of the ESKIMO Test Series (ESKIMO I through VII), which was conducted as part of a continuing program to determine more accurately minimum safe separation distances between earth-covered magazines storing high explosives. The reports for these tests are provided by references 2-10 through 2-18.

C2.3.7.1. **ESKIMO I, 8 December 1971**. Previous testing had demonstrated that earth-covered, steel-arch magazines could be safely spaced side-to-side at a distance of $K=1.25W^{1/3}$. However, little information had been developed to indicate the minimum safe distance to use between the concrete headwall of a magazine and the earth-covered side and rear walls and barricaded headwall of another magazine. The most recent data from the 1962 NOTS Test (reference 2-9) showed that a spacing of $4.5W^{1/3}$ for a front-to-rear orientation appeared to be conservative. ESKIMO I was designed to evaluate the possibility of further reductions of intermagazine distance.

C2.3.7.1.1. **Test Description**. The test required the construction of four acceptor steel-arch magazines constructed per OCE Drawing AW 33-15-64 (their lengths were limited to 20 feet) and one barricade. The donor magazine was a remaining structure from earlier 1963 testing. The acceptor magazines were oriented with respect to the donor, so that the desired relationships (i.e. front-to-side, etc.) could be tested. The donor charge consisted of 200,000 pounds of TNT contained in 13,696 155-mm projectiles. The test was fully instrumented in order to obtain the data described in the test objectives. High-explosive charges were located in each of the acceptor igloos to provide further evidence of the probability of the explosion propagating to the acceptor magazines. Each magazine contained eight acceptor charges, arranged in two rows of four, across the face of the magazine, one about 18 inches off the floor, and the other above it, about five feet off the floor.

C2.3.7.1.2. **Test Objectives**. Principal test objectives for ESKIMO I were: evaluation of igloo intermagazine spacing; measurement of fragment mass and distribution resulting from the mass detonation of typical high-fragmentation ammunition stored in a standard earth-covered igloo; measurement of air blast in the area surrounding such an explosion; and measurement of the structural motion of an earth-covered igloo in response to the explosion in an adjacent magazine.

C2.3.7.1.3. **Test Conclusions**. The principal conclusions arrived at from the test were that earth-covered, steel-arch magazines, without intervening barricades, could be separated in a face-to-rear orientation by $2.0W^{1/3}$ and in a face-to-side orientation by a distance of $2.75W^{1/3}$. In addition, as a result of ESKIMO I data, the DDESB adjusted the spacing for a face-to-face orientation to $11W^{1/3}$ when unbarricaded, and to $6W^{1/3}$, when barricaded.

C2.3.7.2. **ESKIMO II, May 1973**. This was the second in a DDESB-sponsored series of tests, whose main purpose was the evaluation of the protection afforded by five steel-arch acceptor igloo magazines, against communication of explosion, when their headwalls faced a barricaded donor site (bombs in a revetment).

C2.3.7.2.1. **Test Description**. ESKIMO II was a full-scale proof test of other existing and modified door and headwall designs; in this test, the separation distances from a donor stack of bombs, in a revetment, were approximately the same for all five acceptor igloo magazines facing the stack. The donor stack consisted of 72 M117 bombs, with a TNT equivalency of 24,000 pounds. This explosion source was designed to produce an impulse load of 1100 psi-ms on the headwalls of the five acceptor magazines, each located 147 feet away from the explosion source. Two of the three acceptor magazines had no acceptor charges inside them. The remaining three acceptor magazines each contained twelve M15 land mines as acceptor charges. The land mines were positioned in two rows of six, one row approximately three feet from the floor, and the second row was located approximately six feet from the floor. The rows were located three feet from the headwall and door.

C2.3.7.2.2. **Test Objectives**. The objectives of ESKIMO II were:

C2.3.7.2.2.1. Evaluation of the resistance of several types of igloo door and headwall designs, and of proposed modifications to existing door and headwall designs, to withstand the blast environment associated with an explosion. The headwall and door designs tested were one Navy Type II Magazine (NAVFAC Drawing 649-604), with its hinged, double-leaf doors; one proposed non-circular, steel-arch (oval) Army Stradley Magazine (OCE Drawing 33-15-61), with its bi-parting, sliding doors; and three Army steel-arch magazines (OCE 33-15-64), with three different door designs. One was the double-leaf, hinged doors specified on OCE Drawing 33-15-64, the second was a proposed single-leaf, sliding door designed by Black and Veatch and shown on an unnumbered drawing dated 25 October 1972, and the third was a proposed double-leaf, hinged door, with removable steel beam reinforcing, which represented a Black and Veatch modification of the door shown on OCE Drawing 33-15-64.

C2.3.7.2.2.2. Investigation of hazards associated with window glass and window frames placed at several distances from explosions, with the emphasis on using window types common in commercial and institutional buildings.

C2.3.7.2.2.3. Evaluation of blast damage to both foreign and domestic vehicles placed at distances specified by various authorities for public traffic routes.

C2.3.7.2.2.4. Acquisition of data regarding fragment hazards associated with an M117 bomb.

C2.3.7.2.3. **Test Conclusions**. This was an over-test, because the near-field blast loading exceeded that planned. The conclusions from testing were as follows:

C2.3.7.2.3.1. Though there was a wide range of door and headwall responses, no change to DDESB separation distance standards were considered necessary at that time. In addition, the results provided guidance for the selection of promising types of headwalls and doors to be tested more extensively.

C2.3.7.2.3.2. The Black and Veatch single-leaf, sliding door withstood the blast with minor distortion, although the accompanying headwall suffered severe damage. The proposed Stradley-type magazine headwall withstood a face-on impulse of 1,750 psi-msec with only minor damage and its non-circular (oval) steel-arch withstood the blast without breakup or severe distortion. Further, the test reaffirmed a need for achieving a closer balance in the strength of headwalls and doors.

C2.3.7.2.3.3. The test supported DDESB inhabited building and public traffic route distances. North Atlantic Treaty Organization (NATO) distances were questionable.

C2.3.7.3. **ESKIMO III, June 1974**. In this third test of the ESKIMO Series, approximately 350,000 pounds of Tritonal explosives (in M117 Bombs) were detonated simultaneously within a steel-arch, earth-covered igloo flanked by two adjacent igloos and near three other igloos located with varying degrees of face-on exposure and at varying distances from the donor magazine. There were no acceptor charges used in this test.

C2.3.7.3.1. **Test Objectives**. The objectives of ESKIMO III were to:

C2.3.7.3.1.1. Qualify the redesigned oval steel-arch magazine (OCE 33-15-73), at the minimum side-to-side spacing of $1.25W^{1/3}$, which was permitted for semicircular and other standard earth-covered magazines. This was the primary objective of the ESKIMO III test.

C2.3.7.3.1.2. Evaluate a less expensive, deeply corrugated, 14-gage (0.075-inch thickness), semi-circular steel-arch, earth-covered magazine. At that time, the standard gage used for steel-arch construction was 1-gage (0.20-inch thickness).

C2.3.7.3.1.3. Test a single-leaf, sliding door installed on an existing headwall remaining from the 1963 test, at a distance of $2.75W^{1/3}$ from the donor, with a face-to-side orientation.

C2.3.7.3.1.4. Further investigate intermagazine separation distances for other than side-to-side orientation.

C2.3.7.3.1.5. Investigate the hazards associated with window glass located at varying distances (based on DDESB and NATO inhabited building distances) from the donor magazine.

C2.3.7.3.1.6. Evaluate blast damage to highway vehicles placed at public traffic route distances specified by DDESB and NATO criteria, from magazine structures.

C2.3.7.3.2. **Test Conclusions**. The conclusions resulting from the ESKIMO III test were as follows:

C2.3.7.3.2.1. The oval steel-arch igloo (OCE 33-15-73) was qualified, at the minimum side-to-side spacing of $1.25W^{1/3}$ permitted for standard magazines.

C2.3.7.3.2.2. The deeply corrugated, 14-gauge, circular steel-arch magazine design survived the minimum side-to-side spacing, as well. Though the degree of damage was more extensive and arch movement greater than that experienced by the oval, steel-arch magazine, it was considered that the arch structure would have provided protection against explosion communication for common explosives stores.

C2.3.7.3.2.3. The single-leaf, sliding door experienced little damage or deformation and was found to be effective whether mounted on a new structure or on an existing headwall.

C2.3.7.3.2.4. Door and headwall response of the standard magazine OCE 33-15-64 was unsatisfactory at a test separation distance based on $3.7W^{1/3}$. A successful test would have possibly justified a reduction of the required separation distance (based on K6 $W^{1/3}$) for this orientation. However, test results showed that a relaxation of front-to-front criteria (K6 $W^{1/3}$) for this magazine was not warranted. The test consisted of a single barricade between the donor and the acceptor magazines.

C2.3.7.3.2.5. Test results supported DDESB criteria for inhabited building and public traffic route separation distances. [**Note**: In the final report, no conclusions were provided regarding NATO criteria.]

C2.3.7.4. **ESKIMO IV, September 1975**.

C2.3.7.4.1. **Test Description**. In this test, three earth-covered magazine structures each faced an unbarricaded explosion source, located 147 feet away; the source consisted of 37,000 pounds of TNT contained in a hemisphere built of 8-pound blocks. The donor explosion size was selected to duplicate the free-field peak pressure and impulse observed at a scaled distance of $2.0W^{1/3}$, to the rear of the donor magazine in ESKIMO III, which contained M117 bombs filled with a total of 350,000 pounds of Tritonal at full-scale quantity. The three structures tested included; an existing oval, steel-arch magazine used in ESKIMO III, with a single-leaf, sliding door (OCE Drawing 33-15-61); a new circular steel-arch magazine constructed to OCE Drawing 33-15-64, with its specified double-leaf, hinged door; and an existing circular steel-arch magazine used in ESKIMO III, with a rebuilt OCE Drawing 33-15-64 headwall and a single-leaf, sliding door. The second structure described served as the control structure to demonstrate directly the relative strengths of the primary target, which was the oval, steel-arch structure. There were no acceptor charges used in this test.

C2.3.7.4.2. **Test Objectives**. The objectives of ESKIMO IV were:

C2.3.7.4.2.1. To demonstrate the resistance of a newly designed headwall and door combination (the oval, steel-arch magazine with a single-leaf, sliding door) to a blast simulating that possible at the minimum front-to-rear spacing permitted for semicircular and other standard earth-covered magazines. This was the primary objective.

C2.3.7.4.2.2. To test the single-leaf, sliding door installed on a standard headwall (OCE Drawing 33-15-64), at a level of blast loading equal to that experienced by the newly designed headwall and door combination.

C2.3.7.4.2.3. To acquire data on the response of a standard headwall and standard double-leaf, hinged door design to blast loading from a hemispherical charge of TNT, which has well-documented blast characteristics.

C2.3.7.4.3. **Test Conclusions**. Based on test results, the following conclusions were arrived at:

C2.3.7.4.3.1. The blast produced by the donor stack was essentially as predicted and properly simulated conditions at a scaled distance of $2.0W^{1/3}$, to the rear of the donor magazine in ESKIMO III.

C2.3.7.4.3.2. The newly designed headwall and door combination (the oval, steel-arch magazine with a single-leaf, sliding door) responded within acceptable limits and was considered adequate to protect all magazine stores against propagation of explosion under the conditions simulated and blast effects produced in the test.

C2.3.7.4.3.3. The response of the control magazine was as expected, with door failure creating a hazard to more sensitive types of explosive stores, that could prove unacceptable.

C2.3.7.4.3.4. The response of the test circular steel-arch magazine used in ESKIMO III, with a rebuilt OCE Drawing 33-15-64 headwall and a single-leaf, sliding door, showed significant damage to the reinforced concrete headwall and a marked imbalance in strength between the one-piece, horizontally-spanning door and the concrete headwall.

C2.3.7.5. **ESKIMO V, August 1977.**

C2.3.7.5.1. **Test Description**. Test magazines were oriented side-on to the explosion source, at centerline separations of 155 feet. The test was designed to simulate the same loadings on the acceptor magazines as produced by the ESKIMO III donor, where the explosion source consisted of 350,000 pounds of Tritonal (contained in stacked M117 bombs), placed inside an 80-foot long, lightweight, 14-gauge, deeply corrugated, steel-arch magazine. Magazines in ESKIMO III were separated by a scaled distance of $1.25W^{1/3}$. The oval, steel-arch magazine (OCE Drawing 33-15-61) used in ESKIMO II, III (for side-on loading) and ESKIMO IV (headwall loading) was again tested. However, for ESKIMO V, the earth cover was removed, the concrete thrust beams were removed, and the earth cover replaced. ESKIMO V also included a newly constructed magazine of the FRELOC concrete-arch type (Stradley), U.S. Army Engineer Command, Europe, Drawing 33-15-13. Door response was not a concern in the ESKIMO V test; therefore, non-permanent steel doors were spot-welded and/or bolted to the door openings of both test magazines. There were no acceptor charges used in this test.

C2.3.7.5.2. **Test Objectives**. In this test, a hemispherical charge of approximately 75,000 pounds of TNT was detonated with the principal objectives being to justify the removal of concrete thrust beams from an oval, steel-arch igloo and to demonstrate the safety of applying the current side-to-side separation distances to concrete-arch igloos, which had never been tested at those distances.

C2.3.7.5.3. **Test Conclusions**. The ESKIMO V test produced the following conclusions:

C2.3.7.5.3.1. The blast produced by the donor stack was essentially as predicted and acceptably simulated conditions at a scaled distance of 1.25 ft/lb$^{1/3}$, to the side of the donor magazine as in ESKIMO III.

C2.3.7.5.3.2. Structural response of the FRELOC concrete-arch magazine (U.S. Army Engineer Command, Europe, Drawing 33-15-13) was well within acceptable limits, and the structure was considered to be adequate to protect all magazine stores against propagation of an explosion under the conditions simulated and blast effects produced by the test.

C2.3.7.5.3.3. The response of the oval, steel-arch magazine, without concrete thrust beams was also within acceptable limits. Comparison of magazine response from this test to the response of the steel-arch and the concrete thrust beams in ESKIMO III showed that the absence of concrete thrust beams did not significantly affect the response of this type structure under blast loads comparable to, or less than, those of ESKIMO III and ESKIMO V. Based on the test results, thrust blocks were removed from OCE magazine design Drawing 33-15-61.

C2.3.7.6. **ESKIMO VI, July 1980.** This was the sixth in a series of explosives tests involving earth-covered magazine structures. This test was designed to test and evaluate the safety and performance, under blast loading, of two box-shaped storage magazines. These magazines included the existing Navy Type IIB Magazine and the newly designed NAVFAC Type A Magazine. Prior to ESKIMO VI, box magazines in the field had not been tested or specifically designed for overpressure loads. Safety policy, therefore, required that they be sited at non-standard intermagazine separation distances and that their maximum storage capacity be limited to 250,000 pounds of high explosives.

C2.3.7.6.1. **Test Description.** In order to keep the costs associated with ESKIMO VI down, one-half scale test structures were proposed. However, because a box magazine's geometry is so different from an arch-type, earth-covered magazine, it was expected that the blast environment produced by the donor and the effect of the acceptor geometry on loads would be significantly different than those measured for arch-type magazines. Therefore, the U.S. Army's Ballistics Research Laboratory (BRL) conducted 1/50th-scale model tests of box-shaped magazines, to determine the blast environment on the acceptors to the front, side, and rear of a model donor. These are documented in reference 2-16. Pre-shot predictions were developed for nonstandard and standard intermagazine distance for box-type magazines. The donor charge consisted of 60 MK 16 torpedo warheads containing the equivalent of 44,000 pounds of TNT, which corresponded to 350,000 pounds of TNT at full scale, the design charge weight of the new NAVFAC Type A magazine. This charge was placed in a donor structure, which was constructed to simulate the mass properties and geometry of the earth-covered Type IIB magazine. There were no acceptor charges used in this test.

C2.3.7.6.2. **Test Objectives**. The objectives of ESKIMO VI were to:

C2.3.7.6.2.1. Evaluate the safety of existing box-shaped magazines that used non-standard intermagazine spacing. The Navy's Smokeless Powder/Projectile Magazine, Type IIB, Bureau Yards and Docks Drawing 749771, was used to meet this objective because they were in abundant use and had dimensions that were identical to those of the blast-resistant Type A magazine. The Type IIB magazine was oriented side-to-side with the donor magazine with a separation distance of 44 feet ($1.25W^{1/3}$).

C2.3.7.6.2.2. Demonstrate the safety of the new NAVFAC box-magazine designs for use at standard intermagazine spacing. The structure that was tested was the new Box Magazine, Type A, NAVFAC Drawing 1404000, which had been designed to resist the blast loads associated with standard intermagazine separation distances. In the test, the rear of the Type A magazine was oriented to the front of the donor magazine at a separation distance of 70.5 feet ($2.0W^{1/3}$).

C2.3.7.6.2.3. Develop improved load criteria, structural performance requirements, and appropriate intermagazine spacing criteria for box-shaped magazine roofs, walls, and doors. The new NAVFAC Type A Magazine and its single-leaf, sliding doors were selected to meet this objective.

C2.3.7.6.3. **Test Conclusions**. The ESKIMO VI test produced the following conclusions:

C2.3.7.6.3.1. The safety and performance of the Type A magazine, under "worst-case" standard intermagazine distance pressure loads was confirmed. The test report noted that the minor damage experienced by the Type A magazine might imply the possibility of reducing steel and construction requirements while still maintaining satisfactory performance under blast loading. The Type A magazine roof had been designed for a maximum support rotation of 2 degrees, in accordance with the tri-service manual on explosion resistant structures (TM 5-1300, NAVFAC P-397, and AFM 88-22, dated Jun 1969) in use at the time.

C2.3.7.6.3.2. It was demonstrated that the Type IIB magazine would sustain only light to moderate structural damage when exposed to non-standard side-to-side intermagazine distance pressure loads. The door design is inadequate for resisting loads generated by a 350,000-pound NEW charge. Redesign of the headwall and door system would be needed to resist such loads. Consequently, non-standard intermagazine separation distance criteria should continue to be used by the Type IIB magazine.

C2.3.7.6.3.3. Loading criteria were developed for box magazines (full-scale) located to the side and forward of a donor. A magazine located to the side of a donor at $1.25W^{1/3}$, as the Type IIB magazine was, can be expected to experience a maximum roof overpressure of 105 psi, with a corresponding impulse of 754 psi-msec. The headwall will experience a peak overpressure of 50 psi and an impulse of 764 psi-msec. A magazine located to the front of a donor at $2.0W^{1/3}$, as the Type A was, can be expected to experience a peak roof overpressure of 360 psi, with a corresponding impulse of 1,312 psi-msec. The headwall will experience a peak overpressure of 50 psi and an impulse of 1,218 psi-msec.

C2.3.7.7. **ESKIMO VII, 5 and 12 September 1985**.

C2.3.7.7.1. **Test Description**. The existing Type A and Type IIB structures remaining from the ESKIMO VI test were utilized for ESKIMO VII. ESKIMO VI had demonstrated an ample, possibly excessive margin of safety in the Type A magazine roof. ESKIMO VI also had shown that the door system design of the Type IIB magazine was inadequate to resist the loading resulting from a detonation of 350,000 pounds in a similar magazine located at the minimum side-to-side spacing. To address these two areas, two tests were conducted: TEST A-ROOF and TEST IIB-DOORS. There were no acceptor charges used in these tests. Details of the test and the results are provided in the test report (reference 2-17).

C2.3.7.7.2. **Test Objectives**. The objectives of these two tests were to:

C2.3.7.7.2.1. Validate the performance of a redesigned door and headwall system for the Type IIB magazine, under blast loading conditions approximating those at the minimum side-to-side spacing of earth-covered magazines.

C2.3.7.7.2.2. Evaluate the reserve strength inherent in the Type A magazine design at roof slab deformations corresponding to large rotations at supports.

C2.3.7.7.2.3. Provide test data to support improved load criteria, structural performance requirements, and design methods for the roofs, walls, and doors of more economical box-shaped magazines that can be sited at the minimum separation distances permitted by explosives safety standards.

C2.3.7.7.3. **TEST A-ROOF, 5 September 1985**. To produce the required airblast loading on the roof, it was necessary to accurately simulate the overpressure component of the airblast generated by a high explosive surface burst. To accomplish this, a test procedure called the High Explosive Simulation Technique (HEST), developed by the Air Force Weapons Laboratory for the Defense Nuclear Agency (DNA), was used to produce the required blast overpressure and impulse on the roof of the Type A magazine. This technique involved distributing a high explosive over a relatively large surface area and covering the explosive with a soil overburden. The HEST charge density used for TEST A-ROOF was designed to produce a peak overpressure of 800 psi and an impulse of 2,300 psi-msec.

C2.3.7.7.3.1. **TEST A-ROOF Results**. The average measured impulse was 2,500 psi-msec. Both internal columns catastrophically collapsed, changing the roof configuration from a flat slab (with column supports) to a rectangular two-way slab restrained on only four sides. The permanent center deflection at midspan of the roof was 45.5 inches. Both the back wall and headwall were forced inward with the maximum inward displacement being 8 inches and 2.5 inches for the back wall and rear wall, respectively. The performance of the Type A test structure in ESKIMO VI demonstrated an ample, possibly excessive margin of safety in the Type A box magazine roof, which had been initially designed for a maximum support rotation of 2 degrees (**Note**: Based on ESKIMO VI test results, allowable roof rotations was subsequently increased to 8 degrees.)

C2.3.7.7.3.2. **<u>TEST A-ROOF Conclusions</u>**. In summary, because the columns failed, it was not possible to directly assess the inherent ultimate rotational capacity of the box magazine flat slab configuration. What could be concluded was that support rotations of slabs are possible beyond the 8-12 degree range if tensile membrane behavior can be mobilized. It was noted that these large rotations occurred without the presence of any roof shear reinforcement. The NAVFAC box magazines are now designed for maximum support rotation of 8 degrees. Additional information on the test results and conclusions arrived at are provided in reference 2-18.

C2.3.7.7.4. **<u>TEST IIB-DOORS, 12 September 1985</u>**. As part of this test, the door/headwall combination was redesigned to address problems found as a result of ESKIMO VI. The doors were designed for a maximum allowable support rotation of 12 degrees. The hemispherical donor charge consisted of 13,616 pounds of TNT, located to the side of the Type IIB magazine being tested, at a distance of 108.6 feet from the magazine headwall centerline. This charge and distance was calculated as providing a blast environment similar to that observed in the ESKIMO VI test.

C2.3.7.7.4.1. **<u>TEST IIB-DOORS Results</u>**. The redesigned door and headwall system remained intact and more than satisfied the explosives safety deficiencies uncovered with the previous door and headwall system in ESKIMO VI. The maximum door responses measured for the two doors were 2.5 and 3.6 degrees, well below the allowable 12 degrees.

C2.3.7.7.4.2. **<u>TEST IIB-DOORS Conclusions</u>**. Upgrading the explosives safety integrity of older box type magazines can be accomplished by replacing the double leaf hinged doors with sliding (built-up) single leaf doors supported along the door sides and top by a strengthened reinforced concrete headwall. Additional information on the test results and conclusions are provided in reference 2-18.

2.3.7.8. **<u>ESKIMO SERIES TEST SUMMARY</u>.** The ESKIMO tests:

C2.3.7.8.1. Validated the acceptability of using a side-to-side spacing of K1.25 for earth-covered, arch-type magazines, for hazard division (HD) 1.1 NEW up to 350,000 pounds. [**Note**: The DDESB subsequently determined that the results of the ESKIMO Series were valid for HD 1.1 NEW up to 500,000 pounds.]

C2.3.7.8.2. Showed that the roofs of flat-roofed magazines needed specific design considerations (ESKIMO VI and VII).

C2.3.7.8.3. Showed that the headwalls and doors of some of the magazines in use at the time (i.e., the magazine described in OCE Drawing 33-15-61) required strengthening to qualify for storage of 500,000 pounds NEW, at the reduced intermagazine separation distances eventually approved for "standard" magazines.

C2.3.7.8.4. Indicated that several of the magazines in use at the time, and separated by the intermagazine distances at which they were originally built, could safely contain up to 500,000 pounds NEW of HD 1.1 material. Prior to the ESKIMO tests, Army magazines and unbarricaded Navy magazines were typically separated by 400 to 500 feet. Barricaded Navy magazines were typically separated by 185 feet.

C2.3.8. **NAVAJO Depot Activity, Flagstaff, Arizona, 1979 Tests**.

C2.3.8.1. **Test Description**. Full-scale field tests were conducted in 1979, by the Ballistics Research Laboratory, to characterize the hazards to an exposed site when either a 150-pound or 450-pound TNT charge, positioned inside earth-covered, reinforced-concrete igloos, were statically detonated. Test results took the form of airblast profiles and concrete fragment distributions in terms of densities, weights, and their locations relative to igloo orientation. These tests were conducted at the NAVAJO Depot Activity near Flagstaff, Arizona, using igloos constructed in 1942 to Army standards. The tests are described in reference 2-19.

C2.3.8.2. **Test Objective.** The objective of these tests was to demonstrate that the NATO Explosives Safety Manual, which required a minimum of 400 meters (1,312 feet) between inhabited buildings and igloos containing HD 1.1 AE, was overly conservative for small quantities of explosives in magazines. No minimum quantity of AE was associated with this 400-meter restriction.

C2.3.8.3. **Test Conclusions**. The conclusions reached in the Flagstaff tests were:

C2.3.8.3.1. The 400-meter minimum distance requirement between inhabited buildings and igloos containing HD 1.1 AE is excessive for small explosive charges. This was true for both fragment and peak overpressure hazards.

C2.3.8.3.2. The use of a barricade in front of the headwall and a redesign of the vent stack at the rear of the igloo would have reduced the density of hazardous fragments to an insignificant level.

C2.3.8.3.3. The peak overpressure and fragment hazards to the sides and rear of earth-covered igloos are significantly less than those to the front for relatively small explosive weights. These directional effects should be considered when establishing minimum distance requirements.

C2.3.8.4. **Test Result**. Though these tests were initially conducted to support a hazards analysis for a particular activity, the results of the test were subsequently used to support changes to the NATO Explosives Safety Manual.

C2.3.9. **HASTINGS Igloo Hazards Tests for Small Explosive Charges, Hastings, Nebraska, 1984**. The Hastings testing was conducted to supplement, with additional full-scale testing, the Flagstaff testing described in the previous paragraph.

C2.3.9.1. **Test Description**. These tests were conducted at the then Nebraska State National Guard Weekend Training Site near Hastings, Nebraska, using 12 excess, standard-size igloos built to Navy standards. The test igloos were abandoned structures. Prior to testing, these igloos all had developed hairline cracks on all walls and their arches. There was also erosion of the earth-cover that was observed on many of the structures due to lack of maintenance. An earth-backed concrete blast shield (barricade) fronted each test igloo. The igloos' headwall thickness was 8 inches. The test report is provided by reference 2-19. Test results are in the form of overall structural response, airblast measurements, and hazardous fragment distribution for explosive charge weights from 5.4 kg (12 pounds) to 68 kg (150 pounds).

C2.3.9.2. **Test Objectives**. The objectives of the Hastings tests were to:

C2.3.9.2.1. Determine the explosive quantity which, when detonated inside a standard-size, earth-covered igloo, produces no significant external effect.

C2.3.9.2.2. Evaluate the dispersal of structure debris and measure external airblast for the range of explosive quantities up to 68 kg (150 pounds).

C2.3.9.3. **Test Conclusions**. Test conclusions were:

C2.3.9.3.1. The maximum distance requirements between inhabited buildings and standard-size, earth-covered igloo magazines containing small explosive charge weights will be determined by door displacement and not by concrete fragments from the headwall. Blast shields (front barricades) will reduce this distance and change the critical direction of the hazard from the front to the sides, at small charge weights.

C2.3.9.3.2. Blast shields are effective in controlling concrete fragment hazards from the headwalls at explosive charge weights up to 18 kg (39.6 pounds). At higher explosive charge weights, significant numbers of fragments will be projected over the blast shield.

C2.3.9.3.3. Igloo magazines will suffer severe structural damage when explosive charges as small as 5.4 kg (12 pounds) TNT detonate inside a magazine. An explosive charge weight of 7.3 kg (16 pounds) can completely destroy an igloo.

C2.3.9.3.4. There are no significant overpressure hazards, outside of a magazine, associated with the detonation of up to 68 kg (150 pounds) TNT inside a magazine.

C2.3.10. **Summary of Flagstaff and Hastings Testing**. The tests described above that were conducted at NAVAJO Depot Activity, Flagstaff, Arizona, in 1979 and at Hastings, Nebraska, in 1984, were conducted to determine if the (then current) NATO fragment criteria of 400 meters should apply for small amounts of explosive material in earth-covered magazines. Based on the results of these tests, DDESB siting criteria for standard ECM containing small quantities of explosives (less than/equal to 450 pounds NEW of HD 1.1) were revised to permit the use of lesser inhabited building and public traffic route distances.

C2.3.11. **Modular Igloo Test, 1988**.

C2.3.11.1. **Test Description**. The Modular Igloo that was tested by the Air Force, in 1989, at the Utah Test and Training Range (UTTR), was constructed of precast reinforced concrete panels and had a box shape. The intent of the test was to evaluate the design for possible certification as a standard ECM, for allowable storage NEWs up to 500,000 pounds of HD 1.1. The test involved one modular donor igloo with 500,000 pounds NEW of HD 1.1 and four modular acceptor igloos. Three of these acceptor magazines contained explosives-loaded MK 82 (48 each in two magazines) and MK 84 (36 in the remaining magazine) bombs. The fourth acceptor magazine contained empty AGM-65 Missile Containers. The acceptor magazines were sited to the front, sides and rear of the donor magazine, at required minimum separation distances for standard magazines. Data to be collected from the test included blast overpressure, structural and ground acceleration measurements, and limited debris collection. The test is documented in reference 2-20.

C2.3.11.2. **Test Results.**

C2.3.11.2.1. Based on results of this test, the DDESB did not accept the Modular Igloo design as a standard ECM. The primary reason for rejection was that the roof of an acceptor magazine collapsed and a second magazine fell within the crater produced by the donor. Though there was no propagation of any of the acceptor charges in any of the acceptor magazines, the DDESB felt that the damage experienced by the two severely damaged acceptor igloos fell outside the level of acceptable damage to an acceptor standard magazine. The DDESB suggested that the Air Force re-design the roof and then utilize a High Explosive Simulation Test (HEST) to validate the modified roof design. This was done and is reported in reference 2-21. As a result of successful redesign and HEST Testing, in 1994 the DDESB granted final approval to the Modular Storage Module (previously called the Modular Igloo or the Hayman Igloo) as a standard ECM. At that time, the MSM design was documented via several separate drawing packages developed by the AF. In 1999, these separate drawing packages were consolidated by the COE into COE Drawing 421-80-06. The design was also modified to incorporate a lightning protection system.

C2.3.11.2.2. In January 2002, the Air Force Safety Center (AFSC) discovered a serious problem with the MSM design as documented in Drawing 421-80-06. The door design contained in the drawing did not correspond with the acceptor door design documented in the 1989 test report. The translation error appears to have occurred during development of the initial AF Drawings. As a result, a 2 December 2002 DDESB-KT memorandum, Subject: "Removal of 7-Bar Designation from the Air Force Modular Storage Magazine and Actions being taken to restore the 7-Bar Designation to both Existing and New MSM Construction," was sent out. The AFSC quickly set up a design engineering team to review the situation and develop a fix. In early April 2002, the AFSC submitted their proposed solution to the DDESB for review and on17 April DDESB-KT issued a memorandum, Subject: "Approval of 7-Bar Structural Strength Designation for Modular Storage Magazines (MSM) constructed to modified U.S. Army Corps of Engineers

Drawing 421-80-06," which approved a modified 421-80-06 design with the correct door and details for retrofitting new hinges onto the headwall for the heavier doors.

C2.3.12. **Reexamination of Airblast and Debris Criteria, 1991.** A reexamination of the airblast and debris produced by explosions inside earth-covered igloos was conducted in 1991, at the request of the DDESB, by the Naval Surface Warfare Center. This reexamination reviewed available airblast and fragmentation/debris data produced by explosions within standard ECM. The intent of this review was to recommend possible changes to the standards and to provide the best predictive tools for both fragmentation and airblast. Based on the review of data available at that time, this study determined that the present criteria for airblast appear to be safety conservative. It was discovered that there is a major deficiency in the data relating to the debris/fragmentation produced by explosions in ECM. The report of this reexamination can be found in reference 2-22. [**Note**: Facility debris studies based on data obtained from UK, Australian, and U.S. tests conducted since 1991, indicate that safety criteria based on facility debris distances are not conservative. Additional studies and testing are on-going in the debris arena.]

C2.3.13. **Expected Blast Loads from an ECM**. By 2000, the Army and Navy based their design loads for headwalls and roofs of their respective ECM designs on large-scale field tests that had been conducted. For the Army, this was Eskimo 1 and 3 (arch-shaped ECM's), whereas for the Navy, it was Eskimo 6 and 7 (box-shaped ECM's). The version of reference 1-1 at that time did not accurately reflect the design loads indicated by field tests and needed to be revised to do so. As a result, the DDESB (reference DDESB-KT Memorandum of 5 July 2000, which was the Decision Sheet for 316th DDESB Meeting) approved minimum DoD ECM design considerations and blast loads, which have since evolved to the following (from Change 2, reference 1-1, August 21, 2009):

"*C5.2.1.2. ECM must be designed to withstand the following:*

*C5.2.1.2.1. Conventional (e.g., live, dead, snow) loads for the barrel of an arch-shaped ECM.*

*C5.2.1.2.2. Conventional (e.g., live, dead, snow) and blast-induced loads for the roof of a flat-roofed ECM.*

*C5.2.1.2.3. Conventional (e.g., live, dead, snow) loads for the rear wall of an arch-shaped ECM and for the rear and side walls of a flat-roofed ECM.*

*C5.2.1.2.4. Expected blast loads, as applicable:*

*C5.2.1.2.4.1. On the head wall and door of 3-Bar ES ECM is a triangular pulse with peak overpressure of 43.5 psi [3 bars, 300 kPa] and impulse of* $11.3W^{1/3}$ *psi-ms [*$100Q^{1/3}$ *Pa-s].*

*C5.2.1.2.4.2. On the head wall and door of 7-Bar ES ECM is a triangular pulse with peak overpressure of 101.5 psi [7 bars, 700 kPa] and impulse of* $13.9W^{1/3}$ *psi-ms [*$123Q^{1/3}$ *Pa-s].*

*C5.2.1.2.4.3. On the roof of a flat-roofed Undefined, 3-Bar, or 7-Bar ES ECM is a triangular pulse with peak overpressure of 108 psi [7.5 bars, 745 kPa] and impulse of* $19W^{1/3}$ *psi-ms [*$170Q^{1/3}$ *Pa-s].*"

C2.3.14. **High Performance Magazine (HPM).** The Naval Facilities Engineering Service Center (NFESC), Port Hueneme, CA, developed the HPM design with a primary goal of reducing the encumbered land associated with an explosives storage site. They were able to accomplish this goal through the design of a facility that used non-propagation wall (NPW) technology, developed by NFESC to limit the maximum credible event (MCE) to the amount of AE in one storage cell plus the amount of AE that might be present in the shipping/receiving area. The MCE associated with the HPM design reduces the inhabited building distance by 60% and the amount of encumbered land by 80%, as compared to a typical ECM containing the total quantity of AE that could be located in all the storage cells of a HPM. Another touted benefit of the HPM design was that it permitted the storage of non-compatible material within the same storage structure, though in different storage cells. The basis of design for the HPM is provided by reference 2-23. Based on the results of the testing described below, the DDESB granted approval of the HPM as a 7-Bar magazine (and adopted the AE Sensitivity Group (SG) principles discussed later in this chapter) at its 319th Board Meeting on 27 January 2000.

C2.3.14.1. The following testing/analyses were conducted to prove out the HPM concept:

C2.3.14.1.1. In FY93, NFESC conducted two full-scale explosive tests, which demonstrated the explosives safety performance of the NPW concept.

C2.3.14.1.2. In FY95 and FY96, NFESC conducted two full-scale magazine certification tests (CT1 and CT3), to certify explosives safety of the prototype design of the HPM. These tests confirmed that the HPM design prevents sympathetic detonation under the two most critical hazard scenarios. CT1 tested the MCE in a covered storage area (30,000 pounds NEW of HD 1.1) to obtain the maximum cell wall loading. CT3 tested the MCE in uncovered storage/transfer (60,000 pounds NEW of HD 1.1 (total) in the Shipping/Receiving Area, the open storage cell, and the crane load) to obtain the greatest loading on a storage cell. The Test Plan and Debris Density Report for CT1 are provided in references 2-24 and 2-25. Planning and results of Certification Tests CT3 and CT2 (described below) are provided in reference 2-26.

C2.3.14.1.3. A certification test of the pit cover (CT2) was conducted to certify the required cross section of the storage cell cover for preventing fragment penetration.

C2.3.14.1.4. Analytical modeling was used to certify the explosives safety of the prototype design for an MCE fire in either the Shipping/Receiving Area or a storage cell

C2.3.15. **NPW Technology**. The following summarizes critical areas associated with the HPM's NPW design and the basis for the criteria associated with it, as well as the evolution of that knowledge base to other NPW application. Detailed information about development of NPW sympathetic detonation (SD) criteria, the method for classifying munitions into the five SG, and the method for designing composite NPW can be found in references 2-27 and 2-28. Background information summarizing the knowledge base behind the NPW and SG technology is provided in reference 2-29. The preliminary design document developed by NAVFAC for construction of an HPM is provided by reference 2-30.

C2.3.15.1. **<u>SD Criteria Development</u>**. Flyer plate impact tests were conducted to determine reaction thresholds for groups of ordnance items with similar sensitivities. Detailed information on the testing that was conducted can be found in reference 2-27. In summary, ordnance tested in the flyer plate impact tests were representative of the ordnance to be stored in the HPM including the MK 82 bomb, MK103 and MK107 torpedo warheads, the WAU-17 Sparrow missile warhead, the M864 projectile, CBUs, and the TOW II missile. The results of those impact tests were used to establish 5 Sensitivity Groups (SG) [Table 2-1] and their associated prompt SD threshold criteria [Table 2-2]. All HD 1.1 and 1.2 AE are appropriately classified into one of the 5 SGs in accordance with the protocol given in reference 2-31. These thresholds limit the applied unit impulse and energy loads on acceptor ordnance in order to prevent SD. Sympathetic detonation design criteria are based on allowable unit impulse loads, the unit kinetic energy of the NPW, and the NPW velocity, which must all be less than or equal to the threshold limits of the acceptor ordnance in order to prevent SD.

Table 2-1: **Sensitivity Groups and Critical Acceptors**

| Sensitivity Groups (SG) | | Storage Compatibility Group (SCG) | Ordnance Description | Critical Acceptor Ordnance |
|---|---|---|---|---|
| SG # | Description | | | |
| 1 | Robust | C, D, E | Bombs, Projectiles, Thick-Case Munitions | MK82, MK83, MK84 Bombs<br>M107-155mm Projectile<br>WALLEYE[1] |
| | | J | Ammunition with both Explosives & Flammable Liquids | HARPOON<br>TOMAHAWK |
| 2 | Non-Robust | D, E | Thin-Case Items: Most Missiles, Rockets Underwater Mines & Torpedoes | MK103/ MK10 Torpedo Warheads<br>MK55 Underwater Mine |
| 3 | Fragmenting | D, E | Fragmenting Missile Warheads | WAU-17 Sparrow Warhead |
| 4 | Cluster Bombs/ Dispenser Munitions | D, E | Cluster Bombs, Dispenser Munitions | M483 Bomblet<br>Gator Bomblet |
| | | J | Ammunition with both Explosives & Flammable Liquids | TOMAHAWK |
| 5 | SD Sensitive | B | Detonators and Initiating Devices | #8 Blasting Cap |
| | | F, G | Fireworks, Incendiary, Illuminating, Smoke or Tear Producing Munitions; Ammunition with Initiation Devices | M106 Grenade<br>M61 Grenade |
| | | C, D, E | Demolition Explosives, Very Thin-case items; Sheet Explosives, Sensitive Non-Robust | M118 PETN & MK36 H6 Demo Blocks<br>TOW/HELLFIRE[1] |

Note: [1] Directed Energy Weapon Stowage plan must orient directed energy jet away from the NPW.

Table 2-2: **Summary of SD Threshold Criteria for Sensitivity Groups**

| HP Magazine Sensitivity Groups | | Unit Impulse and Energy Loads | |
|---|---|---|---|
| Group No. | Group Description | Impulse, $I_{thres}$ (psi-sec) | Energy, $KE_{thres}$ (ft-k/in$^2$) |
| 1 | Robust | 45 | 24.5 |
| 2 | Non-Robust | 67 | 24.5 |
| 3 | Fragmenting | 53 | 8.49 |
| 4 | Cluster Bombs/ Dispenser Munitions | 25.6 | 3.77 |
| 5 | SD Sensitive | 5.23 | 0.3 |

C2.3.15.2. **NPW Criteria Development**.

C2.3.15.2.1. The most important factor in the improved performance of the HPM is the reduction of the MCE to a detonation involving only a fraction of the total quantity of explosives stored in the HP magazine. This performance is achieved through the use of specially designed NPW and cell covers that prevent prompt SD caused by primary fragment impact, air shock, and heat flux.

C2.3.15.2.2. The NPW design eliminates the hazards associated with NPW debris impact and resulting kinetic trauma. The primary hazard to acceptor ordnance in the HPM is the secondary debris generated by NPW and cell covers as they break up under loading. During the design effort, these loads were conservatively estimated by transferring the total impulse of the air shock to the mass-velocity of the wall and cover debris. In addition, the calculated energy and mass-velocity of the debris was not reduced to account for dispersion before it impacted the acceptor munitions. Secondary kinetic trauma hazards occur after the acceptors begin moving under the impact loads from the wall debris. As the acceptor munitions move, they impact other ordnance and magazine components, causing kinetic trauma to the acceptors.

C2.3.15.2.3. This kinetic trauma is mitigated by reducing loads on the acceptors (to reduce the free body velocities) and by using “crushable” lightweight concrete in the magazine walls and covers to reduce peak shock loads and create a more uniform loading on the acceptors. The HPM's NPW cell covers, and magazine storage area external walls have been designed to mitigate loads on the acceptors, as follows: NPW use relatively weak and crushable lightweight concrete external panels with heavy granular fill materials (sand and steel shot). The mass of the wall reduces the energy in the moving debris. The weak lightweight concrete, with a high void ratio, crushes on contact with the acceptors to reduce the peak shock loads on the acceptor when it is impacted by wall debris and when it makes contact with magazine walls. The granular fill materials flow around the acceptors, disperse their energy, and reduce the impulse coupling from the wall debris to the acceptors.

C2.3.15.2.4. In addition to the limits on the load environment, a debris velocity limit threshold is applied to non-propagation structural elements. This debris velocity limit is based on the calculated NPW debris velocities from the certification tests (CT1 and CT3) of the HPM. Because these tests provide the best available data on successful prevention of SD, the velocity limit threshold for the NPW in the HPM were established as follows:

330 feet-per-second for NPW wall impulse loads of > 10 psi-sec

500 feet-per-second for NPW wall impulse loads of < 10 psi-sec

C2.3.15.2.5. NPW have not been designed to prevent SD of acceptor ordnance from effects of directed energy weapons, therefore, until such time that an NPW is designed to do so, all directed energy ordnance must be oriented toward an exterior wall of the HPM.

C2.3.16. **NPW Technology and SD Criteria Implementation in New ECM Designs**.

C2.3.16.1. As previously mentioned, NAVFAC published a preliminary design standard for the HPM [reference 2-29], which provides an architectural/engineer (A/E) contractor with guidance to develop a final design which satisfies DoD explosives safety requirements. This preliminary design document states that the first HPM should be considered a prototype facility to resolve any design and construction issues and to establish final standards for future HP magazine construction.

C2.3.16.2. Subsequently, NAVFAC ESC was asked by Atlantic Ordnance Command (AOC) to determine the feasibility of modifying 7-Bar ECMs, which had been approved by the DDESB, using NPW technology. They determined [reference 2-32] that it was feasible to use NPW technology to create a three-bay ECM with a 135,000 lbs NEW HD 1.1 total storage capacity. The two NPWs separating the three storage bays would prevent propagation of detonation between the bays. The MCE would be based on a single bay storage capacity up to 45,000 lbs NEW. This magazine design was designated the Type HP-3B magazine, where the HP defines an ECM which uses NPWs to separate bays, and the 3B indicates that the ECM is divided into three storage bays. No such ECM have been designed to date.

C2.3.16.3. NFESC was then tasked by Marine Corps Air Station (MCAS) Iwakuni and the Corps of Engineers Japan Engineer District (JED) to develop and design a new ECM, which reduced the land encumbered by ESQD. This effort supported the Iwakuni Runway Replacement Project (IRRP). The IRRP was a multi-year construction project, which included reclaiming 531 acres of land from the adjacent bay, relocating an existing runway 0.6 miles from its original location onto the reclaimed area, and relocating all of the existing ordnance facilities. Due to the high cost of the reclaimed land, reducing the land encumbered by the ESQD arcs from storage magazines was a critical planning factor. Using the concepts developed for the HP-3B, NAVFAC ESC developed the Type HP-2B magazine concept [reference 2-33]. The Type HP-2B magazine is an earth-covered, reinforced concrete box with two storage bays, which are separated by a NPW. In case of an accidental detonation in a donor storage bay or during handling operations, the NPWs, the magazine roof, the front headwall, and magazine door were designed to prevent propagation of the detonation to the 2nd storage bay within the ECM. On this basis, the magazine was sited for the NEW in a single storage bay. The maximum NEW that can be stored in a single storage bay is 45,000 lbs. DDESB-PD Memorandum of 13 September 2007, Subject: “Approval for the Type HP-2B Earth-Covered Magazine (ECM)”, approved the HP-2B, with conditions, for use at MCAS Iwakuni, Japan only.

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# C3. CHAPTER 3

## EARTH COVERED MAGAZINE (ECM) DESCRIPTIONS

### C3.1. **GENERAL**.

C3.1.1. Prior to 1997, the terms "Standard" and "Non-standard" were used to designate the structural strengths of ECM and their ability to protect their contents from propagation and damage due to an explosion at an adjacent magazine. Of the two designations, a "Standard" ECM had the greatest structural strength and provided the highest level of protection to its contents, while a "Non-standard" ECM was the weaker of the two and provided the lowest level of protection to its contents. Consequently, a "Standard" ECM was permitted to be sited at reduced intermagazine separation distances and to have a higher HD 1.1 storage capacity of 500,000 pounds NEW of HD 1.1, while a "Non-standard" ECM was required to apply greater intermagazine separation distances and was limited to a smaller HD 1.1 storage capacity of 250,000 pounds NEW of HD 1.1.

C3.1.2. In 1997, the terms "Standard" and "Non-standard" were replaced with the terms "7-Bar", "3-Bar", and "Undefined". The terms "7-Bar" and "Standard" designations are synonymous, as are the terms "Undefined" and "Non-standard". The new structural strength designation of "3-Bar" has no pre-1997 equivalent and was established in recognition of the fact that there could be ECM designs that have greater structural strength than an Undefined ECM, but less structural strength than a 7-Bar ECM. Due to the additional protection offered to the magazine's contents, as compared to that provided by an Undefined ECM, a 3-Bar ECM can be sited using intermagazine separation distance criteria that are not as stringent as those required for an undefined ECM. Separation distance criteria and design criteria for all AE storage structures are found in reference 3-1.

C3.1.3. Chapter 4 provides additional information pertaining to ECM designs that have been constructed, and Tables AP1-1 through AP1-4 identify the known magazine designs (ECM and aboveground) that exist, and the structural strength designation assigned to them. If a particular ECM design is not listed in the tables, then it must be treated as an Undefined ECM, until such time as DDESB approval is obtained for a change in structural strength designation.

C3.1.4. **APPLICABILITY OF REDUCED ECM IBD AND PTR DISTANCES TO NON-STANDARD ECM**. In 1990, the Army's Technical Center for Explosives Safety asked the DDESB Secretariat about the applicability of reduced IBD and PTR distances in Table 9-1, columns 2, 3, and 4, of DoD 6055.09-STD to non-standard ECM. [**Note**: The July 1984 Version of the STD was in use at that time. Table 9-1 has since been changed to delete the column numbers discussed below from Table 9-1, however, the column titles (i.e., front (column 2), side (column 3), rear (column 4) remain unchanged as compared to the current version of DoD 6055.09-STD in use.] The Secretariat's response to the Army's question is documented in DDESB-KT Memorandum of 27 July 1990, which is titled "Application of DoD 6055.09-Quantity Distance (QD) Standards to Non-Standard Magazines". Their response, which remains unchanged to this date, was as follows:

C3.1.4.1. Columns 3 and 4 (side and rear) may be used for a non-standard ECM, provided the magazine cover is equivalent or better than that of a standard ECM, and the ECM's dimensions are 26 feet wide by 60 feet long or larger.

C3.1.4.2. Columns 2, 3, and 4 (front, side, and rear) may be used for a non-standard ECM with dimensions less than 26 feet wide by 60 feet long, provided the MCE loading density is less than or equal to 0.028 lbs/ft$^3$, and the earth-cover is equivalent to or better than that of a standard ECM.

C3.1.4.3. All other default applications of columns 2, 3, and 4 apply only to standard ECM with dimensions of 26 feet wide by 60 feet long or longer.

C3.2. **ECM DESIGN CRITERIA**. An ECM's primary objective is to protect AE. To qualify for the default IMD of reference 3-1, an ECM acting as an ES must not collapse. Although substantial permanent deformation of the ECM may occur, sufficient space should be provided to prevent the deformed structure or its doors from striking the contents. ECM design criteria (blast loads) for a 7-Bar, a 3-Bar, and an Undefined ECM are specified in reference 3-1.

C3.3. **ECM TYPES.**

C3.3.1. **7-Bar ECM**. A 7-Bar ECM provides the highest level of asset protection and permits the use of the least restrictive separation distances. The 7-Bar ECM is approved by the DDESB, for a maximum, allowable NEW of 500,000 pounds HD 1.1. Most 7-Bar magazine designs are of the arch-type; however, there are a number of box-type designs that have been approved as well. The Navy's box-type, 7-Bar ECM designs had been initially approved with allowable NEWs up to 350,000 pounds HD 1.1, however, in 2006, at the request of the Naval Ordnance Safety and Security Activity (NOSSA), and based on the results of a NAVFAC ESC analysis, the maximum, allowable NEW of Navy Box Magazines C, D, E, and F was increased by the DDESB (reference 3-2) to 500,000 pounds of HD 1.1. The Air Force's box-type, 7-Bar ECM (Hayman) is approved with a maximum, allowable NEW up to 500,000 pounds HD 1.1.

C3.3.2. **3-Bar ECM**. The headwall and doors of a 3-Bar ECM are not structurally as strong as those of a 7-Bar ECM, but are stronger than the headwall and doors of an Undefined ECM. As a result, IMD for 3-Bar ECM are generally more restrictive than for a 7-Bar ECM, but not as restrictive as for an Undefined ECM. A 3-Bar ECM is permitted to store up to 500,000 pounds NEW of HD 1.1, unless otherwise noted.

C3.3.3. **Undefined ECM**. An Undefined ECM is the weakest of the three ECM design types specified in reference 3-1. A magazine placed in this structural strength category is either known to be a weak structure or there is insufficient information available for a particular design to prove that it provides greater than “Undefined” protection. Consequently, the Undefined ECM generally requires the application of the greatest IMD. An Undefined ECM is permitted to store up to 500,000 pounds NEW HD 1.1. This has not always been the case, as discussed in C3.1.1 above. Prior to January 1996 (312$^{th}$ DDESB Board Meeting), the maximum allowable explosives limit for an Undefined (Non-standard) ECM was 250,000 pounds NEW and any quantity over 250,000 pounds required the Undefined ECM to be sited as an aboveground magazine.

C3.4. **<u>TYPICAL ECM FEATURES</u>**. A typical ECM has the following typical features:

C3.4.1. A semicircular arch or oval arch constructed of reinforced concrete or steel, or a combination of the two. Arches are not designed to contain the effects of an internal explosion. The only design requirement for the arch is that it be capable of supporting dead loads. [**<u>NOTE</u>**: Most Navy and Air Force ECM designs are reinforced concrete box-type with flat roofs. The flat roof of a box-type ECM must meet blast load requirements of reference 3-1.]

C3.4.2. A reinforced concrete floor slab that is sloped for drainage.

C3.4.3. A reinforced concrete rear wall [**<u>NOTE</u>**: There are existing ECM designs that have no rear wall, but are designed instead with two headwalls. These type magazines are known as “flow-through” designs.]

C3.4.4. A reinforced concrete headwall that extends at least 2-1/2 feet above the top of the ECM. The headwall is designed to withstand the external blast pressures and impulses resulting from an explosion in an adjacent AE storage facility. This is a critical feature that directly contributes to the strength designation assigned to an ECM. The stronger the headwall, the more protection it can provide to its contents. Some designs have two headwalls, rather than the traditional headwall and rear wall (see C3.4.3 above). A headwall’s entrance header and pilasters are strengthened to support the loads transferred from the door when an external blast load impacts it. If the door or headwall fails at the door interface, then the design is considered inferior. However, if the door and headwall survive, but the door in rebound falls to the ground, the magazine is considered to have accomplished its goal. That said, the goal should always be for the door to remain in place following an external explosion at an adjacent AE magazine.

C3.4.5. Reinforced concrete wingwalls on either side of the headwall. The wingwalls may slope to the ground or may join wingwalls from adjacent ECM. The wingwalls may be monolithic (of single construction) or separated by expansion joints from the headwall. The purpose of wingwalls is to retain the earth fill along the side slopes of the ECM.

C3.4.6. Robust steel entrance doors in the headwall, typically constructed of two thick steel plates with reinforcing elements (I or C Beams) placed between them, which are either manually operated or motorized. Approved box-type ECM, to date, have as many as five of these doors in their headwall, while, to date, approved arch-type ECM have as many as two doors on each headwall, though one door is more typical. Doors are either of the swinging (hinged) or sliding type. Sliding doors are generally used on the larger ECM or where a large entrance is needed for the AE being stored, while swinging doors are primarily used on smaller ECM or where it’s not critical to have a large door. Doors are designed to withstand the dynamic forces from an explosion in an adjacent AE storage facility, and are therefore, another critical element associated with the structural rating of an ECM design. Doors are not designed to provide resistance to the effects resulting from an internal explosion. Past designs included single and double hinged doors and single or bi-parting sliding doors. The trend is to provide larger doors to accommodate longer munitions in today’s inventory. Many projects have been initiated to expand the entrance into existing magazine structures. The structural hardness must be maintained when modifying magazine headwalls and/or doors, or there may be a significant penalty associated with the modification (e.g., an existing 7-Bar ECM modified for a larger door must have the replacement headwall and door also rated for 7-Bar, or the design will have to be treated as an Undefined ECM or a 3-Bar ECM if data or analysis so indicates). DDESB site approval is required for the replacement design, prior to commencing work.

C3.4.7. Earth cover over the top, sides, and rear of the ECM. A minimum of 2 feet (24 inches) of earth cover is required over the ECM. The requirements for earth cover are specified in Chapter 5 of reference 3-1. Where allowed by reference 3-1 for permissible exposures, the earth covered sides and rear of an ECM can be considered as barricades. Where insufficient earth-cover exists on top of an ECM, then the ECM must be sited as an aboveground magazine. If earth slope requirements are met, it can be sited as an aboveground, barricaded magazine. [**NOTE**: The use of 2-feet of earth cover on ECM did not become a standard depth until sometime in the early 1940's. Therefore, unless 2 feet of earth cover is provided over an earth-covered magazine constructed prior to 1940, it will have to be sited as an aboveground magazine.]

C3.4.8. Lightning protection and grounding systems are installed and integral to the ECM reinforcing. Reinforcing steel in the walls, floor, and arch or box must be interconnected and bonded together and must have a continuous path to ground. For steel arch-type ECM, the arch is interconnected with reinforcing steel in the floor and walls of the ECM. Continuous bonding of metallic structural components, as described above, produces a faraday-like shield, which shields the contents of the ECM from lightning hazards. Lightning protection criteria are specified in Chapter 7 of reference 3-1. [**NOTE**: No specific design information has been found for grounding and lightning protection systems that were associated with ECM designs from 1928 through 1940.]

C3.4.9. Incoming utilities are installed to meet the construction, installation, grounding, and lightning surge protection criteria of Chapters 6 and 7 of reference 3-1. In general, electrical, communication, and signal wiring will need to be provided underground the last 50 feet to an ECM, in metallic piping that is grounded to the ground counterpoise system prior to entering the ECM.

C3.4.10. When required, internal electrical work and equipment must be rated for the hazardous environments expected within the ECM, in accordance with Chapter 6 of reference 3-1.

C3.4.11. At one time, flappers on ECM ventilators were a standard requirement in ECM design. The flapper is the closure device that is held in the open position with a fusible link. When an ECM is exposed to an external fire, the fusible link melts, allowing the flapper to close and to block off the ventilation openings into the ECM. This action keeps out flames, hot gasses, and burning embers, all of which can threaten the contents of an ECM. For a fusible link to be effective, it has to be located outside the ECM in a location where flames can impinge on it and cause it to function properly. Flappers are no longer required on ECM; however, many ECM still use flappers and fusible links. If used as originally designed, flappers on existing ECM must be secured with a fusible link that complies and is installed in accordance with Underwriters' Laboratory (UL) or Factory Mutual (FM) Systems. Flappers must also be kept free of corrosion. A temperature rating of 160/165 °F is recommended for fusible links used with ECM flappers. If the flappers do not meet these requirements, they should be secured in an open position or completely removed.

C3.4.12. In the case of a box-type ECM, the walls and roof may be constructed of reinforced concrete or of prefabricated concrete panels that are assembled in the field. Earth cover, lightning and grounding criteria described above would also apply to box-type ECM. The use of a NPW is a feature found in a few of the newer box-type ECM designs (used in Japan), to limit the MCE and reduce QD. Figure 4-2 provides an illustration of such a design.

C3.4.13. The only current exception to the typical 7-Bar ECM features described above is the HPM, which consists of multiple barricaded, reinforced concrete storage areas, separated by specially designed non-propagation interior walls, with reinforced concrete covers over the storage areas. Removal of AE from the storage pits involves the use of an overhead crane. Though given a 7-Bar designation, the HPM is not an earth-covered magazine. The HPM is earth-bermed (except for the truck entrance) and moveable reinforced concrete (RC) lids form the roof of each storage cell. The area above the storage cell is enclosed by a lightweight metal panel building, within which is contained the crane used for ordnance movement in the HPM. Additional information about the HPM can be found in C2.3.13.

## C3.5. **ECM DESIGN APPROVALS**.

### C3.5.1. **7-Bar and 3-Bar ECM Design Approvals**.

C3.5.1.1. All new 7- and 3-Bar ECM designs must be approved by the DDESB, before they can be sited as 7- or 3-Bar ECM. A request for approval must be accompanied by supporting documentation to prove the structural strength being claimed for the design. These data can consist of an ECM test report, a detailed structural analysis, etc. In the past, hybrid 7-Bar ECM have been designed, using component features from other 7-Bar ECM designs. This type of ECM design is not considered pre-approved for construction and would require DDESB approval before it could be sited as a 7-Bar ECM. The design of hybrid ECM offers no clear advantages and is not recommended. Close coordination with the DDESB should be conducted prior to the start of a new 7- or 3-Bar ECM design, in order to avoid problems arising that may prevent obtaining the desired structural strength rating.

C3.5.1.2. Once approved, 7- and 3-Bar ECM designs do not have to be re-approved every time they are to be constructed; however, any use of any 7- or 3-Bar ECM design for new construction requires DDESB approval of the site plan, which must clearly identify by drawing number the design being constructed.

C3.5.1.3. Changes to approved 7- and 3-Bar ECM designs are not permitted, without specific DDESB approval of the proposed changes. If there is any doubt about the impact of a proposed change to the structural integrity of a 7 or 3-Bar ECM, only the DDESB can make a final determination of the change's impact on the design.

C3.5.1.4. **IMPORTANT**. When using an approved 7- or 3-Bar ECM design and site adapting it for construction at a new location, identify the core drawing numbers of the ECM design selected for construction on the new drawings. There have been numerous construction projects where the original ECM design drawing numbers were not captured in a new drawing package, and the pedigree of the design was lost, which by default placed the new design into the "Undefined" structural strength category. Significant effort is required to revise a structural strength designation upward from an "Undefined" designation.

C3.5.2. **Undefined ECM Approval**.

C3.5.2.1. New Undefined ECM designs require DDESB approval, to ensure minimum design and construction criteria are met (e.g., earth cover depth and slope, grounding, lightning protection). In addition, any use of an Undefined ECM design for new construction requires DDESB approval of the site plan.

C3.5.3. **Changes to Undefined ECM Structural Strength Designation**. Reference 3-3 may be used to evaluate the blast resistance of headwalls of existing Undefined, steel or concrete arch-type ECM having an internal radius of approximately 13 feet. This reference may also be used for determining the amount of explosives that can be stored in adjacent undefined steel or concrete arch-type ECM (internal radius approximately 13 feet), without creating a blast propagation hazard between ECM. Procedures are provided for determining the adequacy of an undefined ECM headwall to withstand the blast from a known quantity of explosives at a known distance. This is accomplished by comparing the impulse capacities of the various headwall elements (wall, pilaster, and door) to the impulse generated by an imposed blast environment. The results of such an analysis may be used to revise the structural strength designation of an undefined ECM design to another strength designation. DDESB approval of such an analysis is required before an ECM's structural strength designation can be revised.

C3.6. **FOREIGN ECM DESIGNS**. The DDESB has certified some foreign ECM designs as meeting 7-Bar or 3-Bar criteria of reference 3-1. These approvals have typically come through one of the Services as part of a site submission package, such as to construct or site a NATO magazine(s) at a NATO facility jointly operated/shared by U.S. Forces. On occasion, the DDESB has determined that a magazine design was not able to meet 7- or 3-Bar criteria and had to be sited to meet Undefined ECM separation distance criteria. In other cases, foreign magazine designs have been given 7- or 3-Bar designations, for exposure to a maximum quantity of explosives. In excess of that quantity, the magazine is required to be sited as an Undefined ECM. Foreign ECM designs that have been through this process are included in the magazine tables of Appendix AP1. Restrictions and NEW limitations applicable to use of those designs is also provided by AP1.

## C3.7. **REFERENCES**

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3-3. "Guide for Evaluating Blast Resistance of Nonstandard Magazines," HNDED-CS-S-95-01, U.S. Army Corps of Engineers, Huntsville Division, Huntsville, AL, January 1995.

# C4. **CHAPTER 4**

## **MAGAZINE LISTINGS**

C4.1. **GENERAL**.

C4.1.1. Tables AP1-1 through AP1-3 of Appendix AP1 list all known ECM designs. Table AP1-4 identifies all known aboveground magazines and ECM that have been approved with a reduced NEW and/or a reduced QD. Also included in Table AP1-4 are shipping containers that are capable of containing or greatly reducing hazards produced by an explosion of a known quantity of explosives while in the container. For specific shipping containers, this mitigation capability allows the assignment of a hazard classification based on the lesser risk (e.g., MK 663, LD-1000 and LD-2250).

C4.1.2. The tables are set up in a manner to preserve the historical, structural strength designations assigned to magazine designs. A discussion of those structural strength designations is provided in Chapter 3. As a reminder, "7-Bar" and "Standard" structural strength designations are synonymous, as are the structural strength designations "Undefined" and "Non-standard".

C4.1.3. A numerical-first, alphabetical-second methodology was used for listing magazine designs in Tables AP1-1 through AP1-3. This approach was selected because it is expected that users will typically approach these tables first with a drawing number that they are trying to identify. Magazine designs are first listed by their drawing number(s), in ascending order. Since magazine designs usually have multiple drawing numbers associated with them, the lowest drawing number in the magazine design drawing set was used to determine where the magazine design was placed in the numerical list. Those designs that do not have a drawing number(s) then follow, in alphabetical order, after the numeric listing. Table AP1-4 is an exception to this approach, because of the large number of magazine designs for which no drawing numbers exist and the wide variation of magazine and container types listed. To simplify the use of Table AP1-4, the magazine design's MCE has been listed. The MCE may be identified as NEW or TNT equivalence.

C4.2. **ECM DESCRIPTIONS**. Figure 4-1 below illustrates the various ECM cross-section variations (described below) that exist for arch-type ECM. The names associated with those cross-sections are also used in the description fields of Tables AP1-1 through AP1-4.

C4.2.1. **Arch**. Also known as a circular arch. A single radius is used to define the interior face of the arch, which may be constructed of reinforced concrete, steel (corrugated, laminate, or single gage), or a combination of reinforced concrete and steel to form a composite arch (steel interior arch with overlying concrete).

C4.2.2. **Arch, Oval**. This arch is in the shape of an oval, with the lower portion of each sidewall bowing in towards the direction of the centerline. The arch can be constructed of steel, reinforced concrete, or a composite of both. The shape is defined by the use of a single radius for the vast majority of the arch, with a separate radius called out for the lower portions of the arch. The modified FRELOC-Stradley ECM design is an example of an oval-arch ECM.

C4.2.3. **<u>Arch, Semi-Circular</u>**. The sidewalls are elongated with the arch defined by a radius that originates approximately 3 to 5 feet above floor level. A radius originating at the opposite sidewall defines the lower portion of the arch. The arch can be constructed of either reinforced concrete or steel.

C4.2.4. **<u>Stradley</u>**. This reinforced concrete ECM is characterized by vertical sidewalls that blend into the arched roof. Three radii are used to define the arch and the transition from the vertical sidewalls to the roof arch. Another feature of the Stradley ECM is that its walls are significantly thicker at the base of the sidewalls and thinner at the crown of the arch. The Stradley magazine is named after a Mr. Stradley, its designer.

C4.2.5. **<u>FRELOC-Stradley</u>**. The FRELOC-Stradley ECM is constructed of reinforced concrete. Its interior shape is similar to a Stradley ECM, except that the sidewalls and arch have the same uniform thickness. The FRELOC design has it's origins in the late 1960s, in Germany, and was developed by the U.S. Army Engineer Command (Europe) to reduce construction costs and improve its constructability.

C4.2.6. **<u>Modified FRELOC-Stradley</u>**. This ECM design was the first ECM constructed with an oval arch. See the information above for the oval arch.

C4.2.7. **<u>Box</u>**. This term describes any ECM that has an internal box shape. Explosives limits can range from less than a pound NEW of HD 1.1 to 500,000 pounds NEW HD 1.1.

C4.2.8. **<u>Dome</u>**. This shape was used only with the Corbetta ECM. The interior wall of the magazine is circular. The magazine roof is convex, and the magazine diameter is approximately three times the height of the magazine.

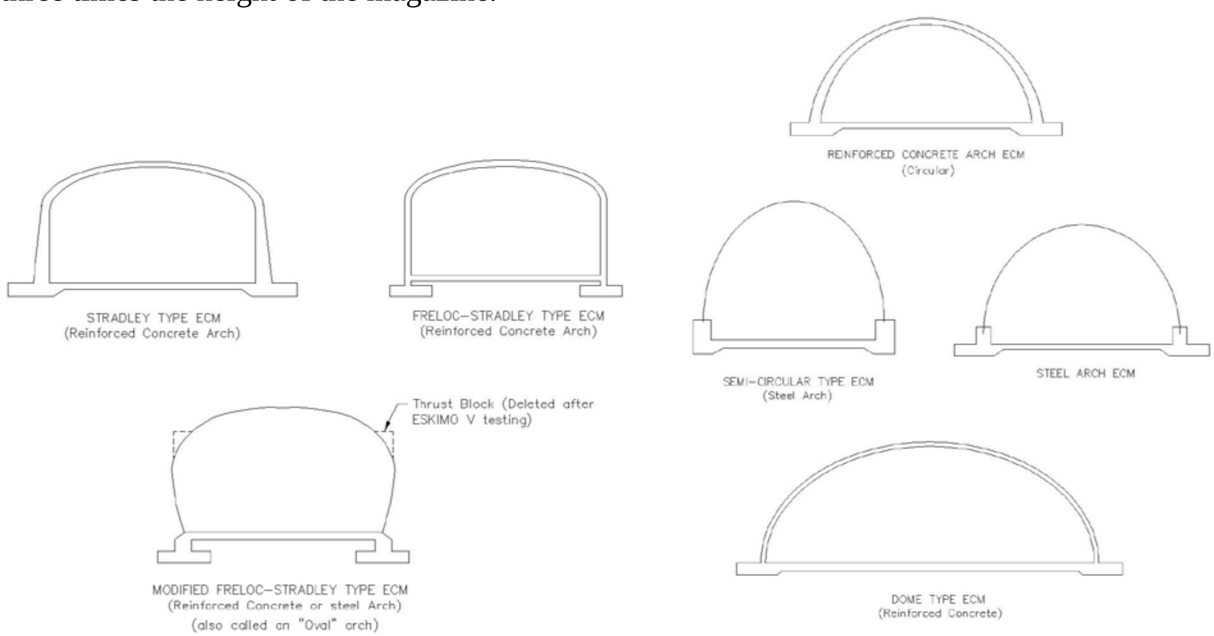


**FIGURE 4-1. <u>ECM CROSS-SECTIONS</u>**

C4.2.9. **<u>HP-2B Box Magazine</u>**. This design is based on the work described in Chapter 2 about HPM, SD and NPW criteria development. The Type HP-2B magazine is a flat-roofed, reinforced concrete box ECM containing two 2 AE storage bays separated by a large NPW. In case of an accidental detonation in one of the storage bays or during handling operations, the design of the NPW, magazine roof, headwall, and magazine doors prevent propagation of the detonation from the donor bay to the adjacent storage bay within the magazine. The magazine may therefore be sited for the NEW in a single storage bay. The floor plan and a cross-section of the HP-2B can be found in Figure 4-2 below.

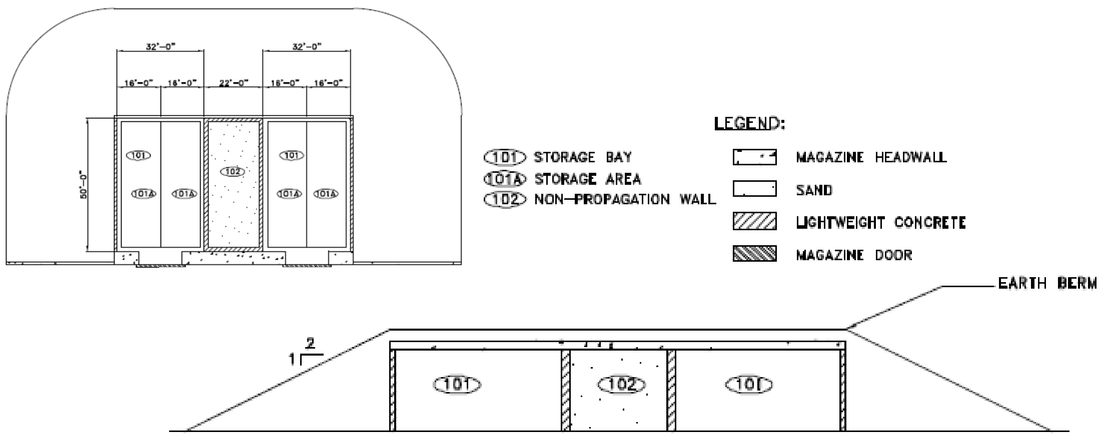


**FIGURE 4-2. <u>HP-2B PLAN VIEW/CROSS-SECTION</u>**

C4.3. **<u>MAGAZINE TABLES</u>** (Found in Appendix AP1):

C4.3.1. **<u>TABLE AP1-1. 7-Bar and 3-Bar ECM Approved for New Construction</u>**. This table identifies all 7- and 3-Bar ECM currently approved by the DDESB for new construction. Also included are a number of foreign-designed ECMs that have been approved as 7-Bar structures. Notes are provided to identify those ECM that have NEW limitations and/or restrictions associated with their DDESB approval.

C4.3.2. **<u>TABLE AP1-2. 7-Bar and 3-Bar ECM No Longer Used for New Construction, But Still in Use</u>**. This table identifies all 7- and 3-Bar ECM that are generally no longer constructed but may still be in use. The table's contents either were previously approved by the DDESB as 7- or 3-Bar (Standard) ECM or were placed into this category by the DDESB as a result of an analysis. In most cases, the restriction on the use of the design for new construction is a result of the Service superceding the design with another design. The information in the table can be used for assistance in siting existing magazines that were previously approved for construction. NEW limitations and/or restrictions associated with their DDESB approval must be observed. Because these designs are no longer actively maintained, they may not comply with current explosives safety criteria. If there is a desire to use a design from this table, and DoD Component approval is obtained, the design may be used for new construction, provided it has been completely evaluated for compliance with current criteria of reference 1-1 and the design drawings updated. DDESB approval of the revised design is required and all changes that have been made must be clearly identified on the drawing.

C4.3.3. **Table AP1-3. Undefined ECM Listing**. Table AP1-3 lists all magazine designs that are considered to be Undefined. This structural strength designation is assigned to an ECM design if it was determined by analysis, testing, or DDESB assessment to be inherently weaker than a 7-Bar or 3-Bar magazine design, or if its structural strength is simply unknown due to a lack of supporting information to prove its ability to meet 7- or 3-Bar criteria. Each DoD Component provides its own guidance as to which of these magazines can be constructed.

C4.3.4. **Table AP1-4. Magazines (Earth-covered and Aboveground) and Containers with Reduced NEWs and/or a Reduced QD**. Table AP1-4 lists AE storage structures and containers that have been approved by the DDESB for specific NEWs and/or reduced QD. The items in this table were generally designed for a particular application; however, as approved items, they can be used by other DoD Components and for other applications, provided all conditions, restrictions, design elements, etc., are observed. All documentation pertaining to the use of the storage structure or container must be obtained prior to their use. Table AP1-4 also identifies restrictions/conditions, as applicable, for use of the items listed.

# C5. <u>CHAPTER 5</u>

## UNDERGROUND AMMUNITION STORAGE FACILITY

C5.1. **GENERAL**. U.S. Army Corps of Engineers Definitive Drawing 421-80-04, dated 18 Nov 96, was approved by the DDESB on 8 December 1996 and provides general advice and guidance in the planning, siting, and construction of underground ammunition storage facilities. This drawing provides details regarding facility layout, tunnel and chamber dimensions, a frontal barricade, closure blocks, and blast doors, as well as on rock classifications. Copies of this drawing can be obtained from the U.S. Army Corps of Engineers, Engineering and Support Center, Code CEHNC-ED-CS-S, P.O. Box 1600, Huntsville, AL 35807-4301.

C5.2. **UNDERGROUND MAGAZINE CRITERIA**. DoD explosives safety and design criteria for underground ammunition storage facilities can be found in reference 1-1.

C5.3. **NATO CRITERIA**. NATO explosives safety and design criteria for underground ammunition storage facilities given in reference 5-1, PART 3, are very similar to those found in reference 1-1, though there are some major differences. The NATO criteria represent the most recent work, but the DDESB has not yet adopted the NATO criteria at this time. NAVFAC ESC was asked to do a comparison of NATO versus DoD criteria and their work is described in reference 5-2. The DDESB is currently assessing the differences and evaluating the adoption of NATO criteria.

C5.4. **REFERENCES**.

5-1. Allied Ammunition Storage and Transport Publication (AASTP)–1, Change 2, "Manual of NATO Safety Principles for the Storage of Military ammunition and Explosives," May 2006
5-2 Conway, R., "Review of NATO Underground Magazine Criteria and Update Recommendations for DoD 6055.09-STD," NAVFAC ESC, TR-2278-SHR, September 2006

# C6. CHAPTER 6

## BARRICADES

### C6.1. GENERAL.

C6.1.1. Hazardous effects produced by an explosion generally consist of airblast, fragments, debris, and thermal. Given sufficient distance from the explosion source, these effects can eventually be reduced to a point where the worst hazard of consideration no longer presents any risk. However, the use of large protective zones is typically not acceptable because of the vast quantities of real estate that would be needed. Consequently, explosives safety criteria of DoD 6055.09-STD (reference 6-1) provide for the minimum required default separation distances for the prevention of propagation (prompt and subsequent) and for the protection of personnel (related and non-related) and assets, after consideration of the type of explosives operation being conducted, the protection level required, the explosives material involved, the type of facilities involved, as well as other factors. For example, personnel exposed to an intentional detonation operation or a high risk operation (e.g., motor firing in a test cell, a detonation range) would require a higher level of protection, as compared to an operation where only an accidental (non-intentional) explosion was expected. Reference 6-1 permits the use of lesser separation distances if DDESB approved protective construction/mitigation is used that is capable of providing an equivalent level of protection to that required at the minimum default separation distance. Testing and/or analyses are necessary to demonstrate to the DDESB that the mitigation method selected is adequate.

C6.1.2. The purposes of this chapter are to consolidate in one location the many protective construction and mitigation methods and designs that have been approved by the DDESB; to provide sufficient information to enable a user of TP 15 to make an initial assessment of the methods available to them for their specific needs; and to provide sources for additional information.

C6.1.3. Conditions and restrictions (e.g., maximum NEW, minimum standoff distances, minimum barricade height, required construction materials) always apply to the use of protective construction and mitigation methods/designs. These conditions and restrictions ensure that any planned use of the method/design falls within the boundaries and parameters that were defined by testing or analyses. Use of one of those methods/designs outside its established boundaries and parameters may yield a different result from that tested and could negate the benefit that was intended. Consequently, it is extremely critical that before a method/design is selected, that all pertinent information and approvals be obtained, read and understood, and all conditions and restrictions followed. Additional testing or analyses may be conducted if there is an interest in evaluating other applications and uses for a specific method/design.

C6.1.4. **Modification of 2-degree barricade height criteria**. The DDESB (reference DDESB-PD Memo of 11 December 2006, Subject: "Approval of Change to DoD 6055.09-STD, Barricade Design Requirements, By Correspondence Vote") approved a change to the barricade design requirements of reference 6-1, specifically for determining the required height of barricades used for intermagazine (K6) protection **against prompt propagation** due to high-velocity, low-angle fragments. The then existing "2 degree rule" was replaced with a requirement that the barricade's height must be at least one foot above the line-of-sight between explosives stacks, with the line-of-sight determined in the same manner as was previously required. Details regarding this change can be found in the DDESB approval document. [**NOTE**: This change does not apply to previous approvals where explosion testing was conducted with a barricade (e.g., Air Force Big Papa test for barricaded module storage described in Chapter 7), where the tested barricade's height was determined using the two-degree requirement.]

C6.2. **BARRICADE DESIGNS**. Barricades are available in many different shapes and sizes, and if properly constructed can be very effective in controlling fragments and debris and, in certain circumstances, blast effects. The various uses for a barricade are described below:

C6.2.1. A barricade can provide an effective means of stopping high-velocity, low-angle fragments that are the primary cause of prompt propagation of an explosion from one explosives site to another explosives site. In the event of an explosion at an explosives site, the presence of a barricade will not necessarily prevent subsequent explosions from occurring at other nearby sites; however, each explosion may be viewed as a separate event.

C6.2.2. A barricade can provide adjacent operations and facilities protection from high-velocity, low-angle fragments, which present a high risk of injury or death to personnel, and a high damage potential to facilities and equipment. A barricade will not provide any protection from high-angle fragments, which can pass over a barricade.

C6.2.3. A barricade can provide limited protection from blast overpressure, in an area immediately behind the barricade. The amount of protection provided by a barricade is governed by the barricade's height and width and the distance the exposure is from the rear of the barricade. Protection increases as separation distance decreases. A barricade is ineffective in reducing blast overpressure at far-field distances, such as those associated with IBD or PTRD.

C6.2.4. In certain situations, explosives safety criteria permit the use of reduced separation distances between explosives sites and from explosives sites to adjacent operations and facilities, when properly constructed, intervening barricades are present.

C6.2.5. Some barricades are designed for specific applications, such as to contain fragments or to minimize potential fragment throw distances. Examples where such barricades could be used are at an ordnance environmental (OE) cleanup site, to protect from an unintentional detonation of an AE item being worked, or at an EOD site where only limited quantities of explosives material will be detonated/burned. Use of such fragment defeating barricades may permit a reduction in QD, by allowing other factors, such as blast overpressure or maximum expected fragment distance, to govern the application of QD.

C6.2.6. When there is a need for AE to be in close proximity to other AE, a barricade can be used to limit the MCE to a single AE item, stack, vehicle, etc. As a result, the QD arc emanating from the site can be reduced because it is based on the MCE involved and not all the AE on-site. The DDESB has approved the use of a number of barricade designs and these are listed below. Barricade design and construction criteria are provided in Chapter 5 of reference 6-1.

C6.2.7. Approved barricade designs.

C6.2.7.1. DEF 149-30-01 Barricades. The Huntsville Division of the U.S. Army Corps of Engineers has developed a definitive drawing, DEF 149-30-01, which provides construction information for numerous barricade designs that can be used to protect facilities and equipment located close to explosives sites from high-velocity, low-angle fragments. The definitive drawing provides details for the construction of a traditional earthen barricade, a sandbag barricades, numerous retaining wall barricades, and other types of barricades. The DDESB approved Definitive Drawing DEF 149-30-01 on 25 February 1992. The various barricade configurations are recognized as effective for the applications shown on the drawings and, consistent with constraints indicated on the drawings, are approved for site-adaptable implementation. Copies of Definitive Drawing DEF 149-30-01 can be obtained from USAESCH (see paragraph C1.3 for their contact details).

C6.2.7.2. Jungle Growth. Dense vegetation can be effective in preventing prompt propagation of an explosion from one explosives site to another, due to the jungle growth's ability to stop high-velocity, low-angle fragments. The density of jungle growth plays an important role in stopping these fragments. On 27 July 1976, the DDESB approved the use of barricaded, aboveground separation distance (K6) between aboveground, unbarricaded explosives storage sites at Andersen Air Force Base, Guam. Their approval was based on testing which showed that high-velocity fragments could be effectively stopped by a medium that had a gross average density of at least 2000 grains/ft$^3$, about four times the density of air at standard conditions. The DDESB approved restricted use of jungle growth as an effective barricade for the storage of relatively insensitive, finished ammunition, such as bombs and separate-loaded projectiles, without fuzes or propelling charges. In addition, a regular program of surveillance is required to ensure that the average gross density of the jungle growth is not compromised.

C6.2.7.3. Earth-filled, Steel Bin-Type Barricades. These barricades, also known as ARMCO Inc. revetments, are earth-filled, steel bins that have been used to separate munitions awaiting scheduled processing; for example, munitions on flight lines associated with aircraft parking/loading operations, or the temporary positioning of munitions awaiting transfer to preferred, long-term storage. These barricades are also used to separate uploaded aircraft. These barricades are typically formed into cells and are designed to limit the MCE (for QD purposes) to the munitions stored in each cell. Criteria were approved during the 314th DDESB Meeting for siting of munitions in ARMCO revetments during flight line "load and unload operations." The DDESB Secretariat maintains a list of the munitions suitable for storage in revetments and has developed a methodology for adding other munitions to the list in the future. The initial list and methodology are documented on an 18 April 1997 DDESB memorandum. The Type A ARMCO Inc. revetment has an allowable MCE of 30,000 pounds NEW of HD 1.1 (prompt propagation protection), and the Type B ARMCO Inc. revetment has an allowable MCE of 5,000 pounds NEW of HD 1.1(prompt propagation protection). Restrictions associated with the use of these ARMCO Inc. revetments are found in reference 6-1. Reference 6-2 is the technical report describing the analyses conducted for the ARMCO revetments. These bin-type barricades can also be used around storage sites and operations area, where use of barricaded intermagazine and barricaded intraline separation distances is allowable by reference 6-1.

C6.2.7.4. Ammunition Quickload and Safeload Programs. These programs were developed by the U. S. Army Project Manager for Ammunitions Logistics, in response to a 1986 DDESB Survey of U. S. Army camps in Korea, which revealed that a number of explosives safety storage violations (primarily involving explosives loaded vehicles) existed in proximity to occupied areas. These programs, through testing, developed barricades to help reduce MCE to smaller NEW that were more manageable and that permitted reductions in QD. These barricades are to be used primarily in Theatres of Operation. The following barricades were developed under these programs:

C6.2.7.4.1. AGAN Steel Panel (ASP) Walling System. The ASP Walling System consists of formed metal sheets, which are joined together to constitute both the permanent framework for the wall and the reinforcement for the concrete that is then poured into the metal framework and allowed to cure. The DDESB approved the use of this system initially on 18 September 1990 and then approved a revised technical data package (TDP) for the Walling System on 25 September 1990. Reference 6-3 is the revised TDP for the ASP Walling System and it details the construction techniques that are required to properly assemble the ASP Walling System. The system permits the parking of 155mm loaded trucks, carrying up to one hundred and sixty (160) 155mm projectiles (M107 or M483) and their associated propellant charges, side-to-side with an intervening ASP Walling System between trucks. This quantity of 155mm projectiles equates to about 2,500 pounds NEW. A minimum of 15 feet must separate trucks. In this configuration, the MCE is the AE on one truck, and QD can be based on this MCE.

C6.2.7.4.2. Sand Grid Wall. The Sand Grid Wall uses commercially available honeycomb grid sections that are expanded and sand-filled, in accordance with the instructions provided in reference 6-4, to construct the barricade needed. Once built up to the required height, the sand grid wall can be used as a barricade to separate individual truck or trailer loads of 155mm artillery projectiles plus their associated propellant charges. Up to one hundred and sixty (160) 155mm projectiles and their associated propellant charges, may be on any truck or trailer, which represents the MCE for QD purposes. A minimum separation distance of 15 feet must be maintained between trucks or trailers. Initial DDESB approval for the Sand Grid Wall was granted on 22 February 1991, for use as a barricade for twenty-one (21) different projectile types and their associated propellant charges. Subsequent DDESB approval for an additional four projectiles and their propellant charges was granted on 24 June 1991. The total number of projectile types permitted to use the Sand Grid Wall barricade is currently twenty-five (25).

C6.2.7.4.3. Geotextile Stabilized Sand Walls as Barricades. A 6 February 1991 DDESB memorandum found acceptable the concept of a stand-alone, geotextile stabilized sand wall barricade, which was at least three feet thick at its crown, provided it could meet lifetime requirements through validated erosion control techniques. This barricade design had to have side slopes exceeding 1.5 horizontal to 1 vertical. Based on this DDESB acceptance, the Project Manager, Ammunition Logistics, at Picatinny Arsenal published a TDP which described methods for constructing three different types of geosynthetic reinforced barricades, using sandy soil as a backfill, as an improvement to ordinary sandbag walls. The TDP, reference 6-5, provides detailed instructions for constructing a double-faced geotextile wall, a geotextile-wrapped sandbag wall, and a geocell wall. It was envisioned that these walls would be used in a Theatre of Operation, to protect and separate ammunition. However, use of these walls is allowed wherever permitted by reference 6-1, for the reduction of separation distances (such as barricaded, intermagazine or barricaded, intraline). Painting of exposed portions of the two-geotextile walls has been found to be essential for barricade longevity.

C6.2.7.4.4. 4.2-Inch Mortar Rack. The 4.2-inch mortar rack is contained in a Container Express (CONEX) container and is built of wooden modules and steel plates, arranged in a specific configuration. Each module can contain one box of two M39A2 Composition B loaded mortar rounds. A steel plate is used to separate rows of modules. A passive fire suppression system is used, which consists of plastic containers filled with a fire suppression liquid that are placed in select spaces in the rack. The sidewalls and roof of the CONEX must be sandbagged, and a door barrier must be constructed in front of the CONEX container. The 4.2-inch Mortar Rack was approved by the DDESB on 30 December 1991. If constructed and used in accordance with reference 6-6, the MCE is one box of two mortar rounds. The rack requires a front IBD arc of 310 feet within a 30-degree arc (+/-15 degrees from the CONEX centerline) and a 100-foot IBD arc around the remainder of the storage site.

C6.2.7.4.5. Improved Loading Configuration for 8-Inch Artillery. A 27 March 1987 DDESB memorandum approved loading configurations for TNT-filled 8-inch (M106) artillery ammunition, with associated propelling charges and fuzes, aboard transport vehicles. Transport vehicles using these approved spacing and shielding configurations are permitted to be parked near each other within a holding area, with the MCE considered one transport vehicle. Reference 6-7 provides details regarding spacing, shielding, and load configurations that were approved.

C6.2.7.4.6. 105 MM Tank Rack Design. A rack was developed for the temporary storage of 105 mm tank ammunition in congested areas, such as when a tank has to be downloaded for maintenance. The rack is designed to limit the MCE to one tank round, which permits the application of a 50-foot IBD arc around the facility containing the rack. The facility has soil cover on its sidewalls, rear wall, and roof and uses a front barricade. The rack/facility design was approved by the DDESB on 23 December 1986. A modification of the initial approval, to add additional 105mm ammunition types to those already approved to be placed in the rack/facility, was approved by the DDESB on 19 March 1987. Reference 6-8 provides construction details for the rack, the facility that contains it, and identifies the 105 mm ammunition types permitted to be stored within it.

C6.2.7.4.7. 105 MM/120 MM Tank Ammunition Download Rack. Several construction options have been developed for the storage of 105 mm and 120 mm ammunition in facilities containing ammunition download racks that are designed to limit the MCE to one projectile only. These facilities use soil containment elements for the sidewalls, rear wall, and roof and have a front barricade. Reference 6-9 provides the specifics for construction and use of the rack designs approved by the DDESB on 21 November 1989. The 105 mm versions of the rack require a 50-foot IBD arc, while the 120 mm versions of the rack require a 75-foot IBD arc.

C6.2.7.4.8. TOW Missile Rack. A 28 April 1989 DDESB memorandum approved the use of the Tube-Launched, Optically-Tracked, Wire-Guided (TOW) Missile Rack. The rack, which limits the MCE to a detonation involving 50 pounds NEW (TNT equivalent), is contained within a CONEX container. The rack is assembled using stacking modules and steel plates between rows, in a manner similar to that described above for the 4.2-inch mortar rack. The CONEX container is sandbagged on the sides, rear, and roof, and a barricade is constructed in front of the door. When assembled and used in accordance with reference 6-10, the rack requires a front IBD arc of 740-foot within a 60-degree arc (+/-30 degrees from the CONEX centerline) and a 350-foot IBD arc is required around the rest of the container.

C6.2.7.4.9. QD Reduction Using Concertainer Barricades.

C6.2.7.4.9.1. DDESB approval memorandum DDESB-KT of 28 October 2002 approved a TDP, reference 6-11, for the use of a HESCO-Bastion ™ concertainer barricade, configured as shown in the TDP, for prevention of prompt propagation between munitions storage cells, each containing 4,000 kg (8,820 lbs) NEW of HD 1.1, when separated by less than the required IM (K6) default criteria. For the NEW quantity involved, K6 separation criteria would normally require an intervening barricade and a separation distance of 124 feet. In a full-scale test using worst-case (SG 5) HD 1.1 and HD 1.3 acceptor munitions, it was demonstrated that an intervening HESCO-Bastion concertainer barricade was capable of preventing prompt propagation of acceptor munitions located at an IMD of 28 feet from the detonation of a donor munition stack containing 4,000 kg (8,820 lbs).

C6.2.7.4.9.2. NATO Nations have conducted significant testing with these types of sand-filled, fabric, wire-reinforced barricades for the construction/protection of forward operating bases (FOB) used in deployed operational scenarios. This testing has shown that significant fragment protection (which can be further enhanced with overhead protection), as well as some overpressure mitigation, is provided by using these type barricades around explosives storage sites in order to reduce both internal (in camp) field distances (FD) and external (off-base) QD. Based on this data, NATO has developed reference 6-12, AASTP-5, NATO Guidelines for the Storage, Maintenance and Transport of Ammunition on Deployed Missions or Operations, which provides criteria associated with barricaded storage sites for up to 8,800 lbs (4,000 kg) and associated QD. In 2007, the DDESB, which is the DoD's ratification authority for explosives safety related documents, with Service agreement, ratified AASTP-5 for use by US Forces in support of NATO operations. Reference 6-13 is an accompanying document for AASTP-5 and was developed to further explain the background data and protection levels associated with the FD given in AASTP-5.

C6.2.7.5. Munitions and Explosives of Concern (MEC) Removal Sites. The Huntsville Center, U.S. Army Corps of Engineers (HNC) has been involved with projects that require the disposal of uncovered/discarded ordnance and explosives from OE Removal Sites. These sites could be on government, public or private lands. Actions that can be taken when an ordnance item is found include detonation on-site or transportation of the item to another site for proper disposal. Safety to the public and to personnel involved in the disposal action is of utmost concern. In response to the need to ensure this safety, HNC was tasked to develop procedures and barricades for blast and fragment mitigation, for use by personnel performing disposal operations. The barricades that have been approved for this purpose are listed below:

C6.2.7.5.1. Minimum QD for OE removal sites. Revision 2 of reference 6-13 had applied a 200-foot minimum safe distance when using the methodology contained within it, for calculating a munition-specific hazardous fragment distance (HFD) or maximum fragment Distance (MFD). Per reference 6-14, the basis for this 200-foot minimum was to keep bystanders from interfering with or being a distraction during munitions response operations. The 200-foot minimum was not based in any way on the hazard from an explosive item to exposed personnel. Because the 200-foot minimum has imposed an undue burden on munitions response operations and was not originally driven by explosives safety concerns, it has been removed from reference 6-13 (Revision 3); instead the calculated HFD or MFD will be used for the specific munition being accessed. Although the 200-foot minimum was not based on hazards from the explosives to exposed personnel, it is important to recognize that interference and distraction from bystanders can pose a concern to the safe conduct of munitions response operations. Therefore, as determined by the DoD Component involved, use of larger distances than those calculated is encouraged wherever feasible.

C6.2.7.5.2. Minimum Separation Distances (MSD) to Non-Essential Personnel When Using the DDESB-Approved Consolidated Shot Method. DDESB-KO Memorandum of 27 October 1998, Subject: “Procedures for Demolition of Multiple Rounds (Consolidated Shots) on Ordnance and Explosives Sites,” approved the procedure given in reference 6-15 for intentional detonation of single or multiple munitions and the determination of safe separation distances for unrelated personnel. In summary, using the prescribed procedures, the safe distance is the greater of K328 (using the total NEW and detonation charge as the NEW) or the MFD shall be the MFD computed for the most probable munition (MPM) for an OE area at a site, and this shall be the MFD for a consolidated shot.

C6.2.7.5.3. DDESB-PD Memorandum of 25 September 2009, Subject: “DDESB Approval of Minimum Separation Distances to Non-Essential Personnel When Using the DDESB-Approved Consolidated Shot Method,” approved the use of the consolidated shots method concept to collection sites. For those situations, the MSD (to nonessential personnel) for unintentional detonations from in-grid collection or consolidation points is the greater of: (a) The largest HFD of any item at the collection or consolidation point, or (b) K40 of the total NEW of all the items at the collection or consolidation point.

C6.2.7.5.3.1. As described in reference 6-15, this procedure orients the rounds horizontally on the ground, in a single layer, and sidewall to sidewall. By doing so, the interaction zone between projectiles points up (vertically), rather than out (horizontally). This orientation limits the effective maximum range of interaction zone fragments since they exit up and therefore at very high (non-optimum) launch angles. The MFD can therefore be based on that for a single round rather than on the greater range of interaction zone fragments. This orientation also controls the number (density) of fragments entering the far field such that the HFD remains that based on a single round. MSD for nonessential personnel for intentional detonations (shots) and for collection/consolidation points are as follows:

C6.2.7.5.3.1.1. The MSD for intentional detonations for nonessential personnel for a consolidated shot is the greater distance of:

(a) The largest MFD of any item in the shot, or

(b) K328 of the total NEW of all items in the shot, to include donor charges.

C6.2.7.5.3.1.2. The MSD for unintentional detonations for nonessential personnel from in-grid collection or consolidation points is the greater of:

(a) The largest HFD of any item at the collection or consolidation point, or

(b) K40 of the total NEW of all the items at the collection or consolidation point.

C6.2.7.5.4. <u>Sandbags to Mitigate Fragmentation and Blast Effects</u>.

C6.2.7.5.4.1. Reference 6-16 was approved by the DDESB on 23 February 1999. This approval permits use of sandbagging procedures for the intentional detonation of munitions up to 155 mm (M107), at OE sites. Only one munition item can be detonated at a time. Detailed guidelines are provided for the selection and use of sandbag enclosures of various thicknesses to mitigate fragments and blast, and for determining minimum withdrawal distances to be used during detonation operations. A methodology is also provided for determining sandbag enclosure thickness and withdrawal distance for a munition item that is smaller than a 155 mm (M107) projectile, but which had not been tested as part of the sandbag test program.

C6.2.7.5.4.2. Since the original release of reference 6-16 in 1998, additional testing has been conducted, the results of which will be included in a planned Revision 2 to the document. Revision 2 will present information related to the use of new double sandbag thicknesses to further reduce minimum separation distances; will provide information explaining the rationale for removing the 200-foot minimum separation distance requirement in favor of new separation distance requirements specific to individual munitions; and will provide requirements for the use of bulk donor charges instead of perforators to initiate the munition. A presentation regarding the background and content of the planned Revision 2 was given at the DDESB Seminar in 2008, Session 7, by Ms. Sue Hamilton, USAESC Huntsville, Title: "Use of Sandbags for Mitigation of Fragmentation and Blast Effects due to Intentional Detonation of Munitions". DDESB approval of the above changes is still required.

C6.2.7.5.5. <u>Open Front Barricade (OFB)</u>. The OFB is designed to defeat the primary fragments of select ordnance, in the event of an accidental detonation that occurs while performing an intrusive operation at an OE removal site. The OFB is not intended for intentional detonations and is not designed for repeated use. The OFB is used by placing it over the UXO being worked on. The OFB is designed for use with ordnance items that generate an explosives weight-to-OFB internal volume ratio of 0.29 pounds/ft$^3$ or less. If the weight-to-volume ratio is met, then the "minimum separation distance (MSD) for unintentional detonation" associated with the OFB is 300 feet from the three covered sides, and default distances from reference 6-1 must be used from the front of the OFB. The OFB consists of an aluminum frame on which aluminum plates can be mounted to form the three sides and roof. The OFB frame is capable of supporting an aluminum plate thickness of up to 2.75 inches. Sandbags are then used, as necessary, to seal off any gaps under the OFB. Reference 6-16 was approved by the DDESB on 9 December 1999 and provides specific guidelines for the use of the OFB and for aluminum plate thickness selection, for the ordnance items that might be encountered at the OE removal site. If the OFB is to be used for any ordnance item that has a weight-to-volume ratio that exceeds 0.29 pounds/ft$^3$, then the appropriate "MSD for unintentional detonation" for that particular munition needs to be determined using an approved analysis method or by testing or default IBD distances of reference 6-1 will apply.

C6.2.7.5.6. Enclosed Barricade (EB). The EB serves the same purpose as the OFB described above, except that it has a front barricade associated with it. The conditions/restrictions for its use are the same as for the OFB and are contained in reference 6-16, as well. The "MSD for unintentional detonation" associated with the EB is 300 feet, all around. The DDESB approved use of the EB on 9 December 1999.

C6.2.7.5.7. Miniature Open Front Barricade (MOFB). The MOFB is a smaller version of the OFB described above. Reference 6-17 provides details on the restrictions/conditions pertaining to use of the MOFB. DDESB approval of reference 6-18 was granted on 14 May 2010. The MOFB defeats primary fragments to its sides, rear, and top and is for use during an intrusive operation at an OE removal site, in the event of an unintentional detonation. Select UXO items for which it is designed are listed in reference 6-18. It can be used for other items provided the NEW does not exceed 2.4 pounds, and an analysis determines that the thickness of aluminum needed to stop primary fragments does not exceed 1.5 inches. The DDESB approval letter explains what analysis has to be performed. The "MSD to the sides and rear of the MOFB is the larger of K40 overpressure distance for the munition with the greatest fragment distance (MGFD) or 3 feet if the TNT equivalent NEW of the MGFD is no more than 0.5 pounds or 74 feet, if the TNT equivalent NEW of the MGFD is greater than 0.5 pounds, but no more than 2.4 pounds.

C6.2.7.5.8. Guide for Selection and Siting of Barricades for Selected Unexploded Ordnance. Reference 6-19 was developed to enhance safety to the public and personnel conducting OE removal operations. It provides guidance to field personnel to assist them in controlling the potential primary fragment hazard generated by a suspected buried explosive filled ordnance item being uncovered. These barricades are not designed to control overpressure. A number of barricade designs are presented in reference 6-19, with guidance given on how to select the best barricade for the job being conducted.

C6.2.7.5.9. Buried Explosion Module (BEM). An analytical method to calculate public and operational personnel withdrawal distances for buried munitions disposal has been developed. The method includes cratering calculations and calculations of the velocity of the fragment as it exits the soil and fragment trajectory calculations using an approved trajectory analysis code. The maximum ejecta radii of large soil chunks produced by the cratering are then calculated with an appropriate safety factor. In order to simplify and standardize these calculations, software has been developed. The theory and the software, which is called the buried explosion module (BEM), are discussed in reference 6-13. DDESB approval of the BEM methodology was given on 3 November 1998, and it has since been incorporated into reference 6-13. In addition, a software version (EXCEL spreadsheet template– now up to Version 6), addresses both burial in soil and burial in water, implements the methodologies, procedures and algorithms discussed in Chapter 6 of reference 6-13 and calculates the following:

- Whether a crater, camouflet or no crater (underwater) is formed
- If formed, either true crater radius or true camouflet radius
- Maximum soil ejecta range
- Fragment exit velocity
- Fragment exit angle
- Maximum fragment distance
- Fragment hazard range
- Airblast at horizontal range entered
- Airblast at Fragment Hazard Range

C6.2.7.5.10. Use of Water for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonation of Munitions. In 1999, the Structural Branch of the U.S. Army Engineering and Support Center, Huntsville (USAESCH), AL, sponsored a test program to evaluate the use of water for fragment and blast mitigation for intentional detonations at OE sites. The program was broken into two phases, with the first phase determining the minimum water depth needed to defeat fragments from four different munitions, and the second phase testing various water containment systems for the four munitions. DDESB memo of 27 February 2001 approved the use of water for mitigation of fragmentation and blast effects due to intentional detonations. The techniques provided in reference 6-21 are approved for field use on OE removal action projects.

C6.2.7.6. Buffered Storage. From 1986 through 1987, the Air Force conducted a series of tests to prove out the concept of "buffered storage", which used specific palletized AE material as a buffer between specified quantities (stacks) of Mk 82 or Mk 84 bombs, in order to prevent propagation between stacks and thereby reduce the MCE. The MCE was based on the NEW in the largest stack, plus the NEW of the buffer material (when HD 1.4 material is used as buffer material, then the HD 1.4's NEW does not need to be included). The QD was determined using the combined NEW. Test results of these tests are recorded in references 6-22 and 6-23. The Air Force received DDESB approval for use of the "buffered storage concept" in ECM, aboveground magazines, and at outdoor storage areas. A 30 April 1990 DDESB-KO memorandum approved 12 buffered storage configurations that were documented on Drawings AFISC 900402A through AFISC 900402L. Initially, the buffer material approved for use consisted of only palletized 20-mm, 30-mm, and CBU 58. DDESB-KT memorandum of 10 May 1990 authorized palletized CBU 71 to be used as a buffer material, and DDESB-KT memorandum of 28 November 1990 authorized the use of palletized CBU 52 as buffers.

C6.2.7.7. Composite (sand-filled foam panel) Walls for Sub-dividing Magazine MCEs.

C6.2.7.7.1. At the 261st meeting (24 April 1972) of the DDESB, there was a discussion regarding the use of sandbag walls, constructed per Defense Nuclear Agency (DNA) criteria, which permitted storage igloos to be subdivided by sandbag walls generally 6 ft. high by 22" wide using a prescribed configuration. At this meeting, a representative of DNA presented a wall system developed by DNA and Dow Chemical Co., to provide equivalent protection as the sandbag wall, and used as a replacement to the sandbag wall. The system consisted of high-density extruded polystyrene (styrofoam) sections that were assembled into walls and which were filled with sand as the wall was erected. The DDESB approved the use of the new wall system at this meeting.

C6.2.7.7.2. The above concept of using polyurethane type walls also found its way into the Blast Tamer Explosive Damping Blast-Wall System used in Air National Guard (ANG) magazine designs listed in Table AP1-4 and defined by drawings ANG-DWG-94-001, ANG-DWG-94-002, ANG-DWG-96-001, ANG-DWG-99-001, and ANG-DWG-00-001. The General Plastics Manufacturing Company, at the request of the Vermont ANG, developed this composite wall system (polyurethane wall panels filled with sand) to allow the ANG to reduce the MCE of ECM to the NEW contained in a single cell, rather than all the ordnance contained in the ECM. The wall was approved by the DDESB for a maximum of 425 lbs NEW, with a reduced IBD arc of 700 feet to the front of the ECM and a reduced IBD arc of 250 feet to the side of the ECM. By reducing the MCE to 150 lbs NEW, the required IBD arcs could be reduced further to 500 feet to the front and 250 feet to the side and rear.

C6.2.7.7.3. The ability of a composite polyurethane panel/sand wall system (as a non-propagation cell wall) to prevent prompt propagation was analyzed for the ANG by the Naval Civil Engineering Laboratory (NCEL) in January 1993, using AUTODYN-2D analysis. The results of their analysis are documented in reference 6-24. In addition, personnel from the Vermont ANG and General Plastics Manufacturing Company gave a presentation on the Blast Tamer design at the 28th DDESB Seminar, reference 6-25.

C6.2.7.8. <u>QD for Ammunition in ISO Containers.</u> A significant study was undertaken in the late 1990s by the DDESB to (a) develop realistic estimates of the safety hazard ranges (e.g., IBD) for accidental explosions of ammunition in ISO shipping containers, and (b) investigate methods for reducing QD for ammunition containers at temporary storage sites. Co-sponsors of the study were the U.S. Transportation Command (TRANSCOM), the Explosives Storage and Transport Committee (ESTC) of the British Ministry of Defence (MOD), and the U.S. Army Corps of Engineers. The study consisted of 2 phases.

C6.2.7.8.1. Phase 1 of the study was an analytical effort, in which QD were calculated using accepted analytical methods. The goals of Phase 1 were to:

C6.2.7.8.1.1. Review the state-of-the-art for establishing QD for munitions in shipping containers.

C6.2.7.8.1.2. Examine the composition of typical container loads of ammunition.

C6.2.7.8.1.3. Develop preliminary, revised QD for ammo containers, based on existing data and the best available hazard prediction methods.

C6.2.7.8.1.4. Identify the most critical needs for additional test data.

C6.2.7.8.1.5. Design a program of experiments to provide the most needed test data and to verify the revised QD.

C6.2.7.8.2. Phase 2 was a program of experiments conducted to provide test data on:

C6.2.7.8.2.1. The effect of the steel ISO container walls on fragment impact velocities against acceptor munitions,

C6.2.7.8.2.2. Safe separation distances between ISO containers to prevent propagation by blast pressures.

C6.2.7.8.2.3. The performance of sand-filled barricades for preventing propagation at the proposed minimum separation distances between containers.

C6.2.7.8.3. As part of the Phase 1 effort, an extensive survey of available literature was conducted to identify and review previous research related to the objectives of the program. This effort was conducted to extract any information that would be useful to the analysis and to avoid duplicating any work previously performed. This search resulted in 613 references being selected for inclusion in the listings, and data from over 2,500 explosion tests being tabulated in spreadsheets. The results of Phase 1 are documented in reference 6-26.

C6.2.7.8.4. The remainder of the study is documented in reference 6-27. The principal conclusions developed from the analyses and experiments were;

C6.2.7.8.4.1. IBD and PTRD for ISO containers with HD 1.1 components are the same as in open storage.

C6.2.7.8.4.2. Calculations indicated that IMD between containers with fragment-producing HD 1.1 components may be reduced slightly by the reduction of fragment impact velocities due to the shielding effect of acceptor container walls.

C6.2.7.8.4.3. IMD for containers with non-fragmenting HD 1.1 components can be reduced by significant amounts - down to a scaled separation of 3.0 ft/lb$^{1/3}$(1.0 m/kg$^{1/3}$) - if there are no highly sensitive munitions (such as M2 demolition shaped charges) in the container loads.

C6.2.7.8.4.4. IBD, PTRD, and IMD values for HD 1.2 munitions in containers (with no HD 1.1 components) are significantly less than indicated by the current standards, according to FRAGPROP calculations. Again, however, the container walls provide only a minor shielding effect, at best, for acceptor munitions.

C6.2.7.8.4.5. The IMD for HD 1.3 material is limited to that necessary to prevent initiation by spread of a fire. Since the containers shield their contents against firebrands, the recommended minimum IMD is 8 ft, for inspection and fire control access.

C6.2.7.8.4.6. "Blast-Tamer" barricades can be easily and quickly constructed by 3 or 4 workers with minimal training. It should also be possible to disassemble this type of barricade and re-construct it elsewhere.

C6.2.7.8.4.7. The slope-sided barricade design did not appear to provide any advantage in blast protection over a normal barricade with vertical sidewalls, except for better stability.

C6.2.7.8.4.8. The use of sand-filled barricades allows ISO containers of HD 1.1 munitions to be spaced at IMD of 20 feet (6 m).

C6.2.7.8.4.9. Barricades with a sand thickness of only 18 inches (0.5 m) are effective in preventing fragment damage between ISO containers of HD 1.1 munitions.

C6.2.7.9. Water Barriers to Prevent Prompt Propagation.

C6.2.7.9.1. The Air Force has requirements to park combat aircraft at airfields in order to meet operational readiness requirements. These parked combat aircraft must comply with minimum airfield requirements and must be separated from each other by IMD (unbarricaded IMD is K11). Properly constructed barricades to defeat the low-angle, high velocity fragments may be placed between the aircraft to prevent prompt propagation and reduce the required separation distance to barricaded IMD (K6). The primary material that is used for such barricades is sand, frequently contained in HESCO bastions. While such barricades are effective, the HESCO bastions can deteriorate in harsh environments and must be replaced. Water has been shown to be an effective fragment mitigating material and several manufacturers make prefabricated blocks which can be filled with water and used to build walls.

C6.2.7.9.2. Reference 6-28 documents a test of a 0.5m (1.64 ft) thick and a 1.0m (3.28 ft) thick water barrier wall to determine if these walls will prevent prompt propagation. The water barriers were constructed of modular blocks that are a commercial off the shelf (COTS) item manufactured by MRP Systems Ltd. UK. The results of this test, therefore, are applicable only to water barrier walls constructed of the COTS modular blocks tested. The donor munitions were two MK 84 bombs and the acceptors were one MK 84 bomb and one AGM-65 Maverick Warhead on the other side of each wall.

C6.2.7.9.3. Although none of the acceptor munitions in the single wall scenario detonated or burned, the evidence of the fragment strikes on the acceptor munitions and witness panel make it inadvisable to utilize a single wall to prevent prompt propagation without further testing. There was no evidence of fragments from the donor bombs striking the acceptor munitions or witness panel on the double wall side, so it was therefore recommended that water barriers constructed using the MRP Systems Ltd.UK modular blocks in the 5 x 3 block configuration or larger be used in order to prevent prompt propagation between combat aircraft.

Additionally, this test shows that the distance between combat aircraft separated by this 1.0m thick water barrier need only be separated by K5 to prevent prompt propagation.

C6.2.7.9.4. DDESB approval, and the conditions/limitations associated with the use of the modular blocks was given by DDESB-PD Memorandum of 27 September 2007, Subject: "Water Barriers to Prevent Prompt Propagation".

C6.3. **<u>SUPPRESSIVE SHIELDS</u>**. A suppressive shield is a vented, steel enclosure, which is capable of controlling or confining the hazardous blast, fragment, and flame effects of internal detonations. Conditions and limitations associated with each design must be followed in order to receive the level of protection described.

C6.3.1. A great deal of interest existed in the 1970s with respect to suppressive shielding, and an extensive manufacturing technology program was undertaken by the Army to design and proof-test several prototype structures and to develop a technology base for suppressive shield designs. As part of this effort BRL, NASA, Southwest Research, Inc., Huntsville Division (COE), and AAI Corporation conducted extensive testing to develop design procedures and analytical techniques for use in suppressive shielding. Reference 6-29 is a product of this effort. Because of the interest in suppressive shielding, the DDESB established a Suppressive Shielding Technical Steering Committee, which included Dr. Zaker of the Secretariat, to review test data and subsequent design documentation. This committee approved five basic suppressive shield designs for use in hazardous operations, and reference 6-29 presents design details for these designs (Groups 3, 4, 5, 6 (A and B), and 81mm (prototype and Milan)), along with engineering guidance on their selection and modification to meet operational requirements. Reference 6-29 includes information on other groups (1, 2, and 7) that, at that time, were either not funded or had not yet received approval because they were still in preliminary design stages. Approval has since been given for a Group 1 suppressive shield that was installed within a production facility at Indian Head Division, Naval Surface Warfare Center (NSWC). Reference 6-29 also provides guidelines and techniques for the design and proof testing of new suppressive shields. Reference 6-30 is a report that contains descriptions of five groups of DDESB-approved suppressive shields and the engineering data and analysis supporting the safety approval recommendations. Copies of the approval documentation are provided in this report. The following describes each approved group:

C6.3.1.1. **<u>Group 1</u>**. Rated for an NEW of 2,000 pounds. Contains all fragmentation and reduces blast overpressure at unbarricaded intraline distance by 50%.

C6.3.1.2. **<u>Group 3</u>**. Rated for an NEW of 37 pounds. Contains all fragmentation and provides K24 protection at 6.2 feet from the shield.

C6.3.1.3. **<u>Group 4</u>**. Rated for an NEW of 9 pounds. Contains all fragmentation and provides K24 protection at 19 feet from the shield.

C6.3.1.4. **<u>Group 5</u>**. Rated for an NEW of 30 pounds propellant material or pyrotechnics or 1.84 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 3.7 feet from the shield.

C6.3.1.5. **Group 6A**. Rated for an NEW of 0.962 pounds TNT equivalent. Contains all fragmentation and provides K24 protection at 1-foot from the shield.

C6.3.1.6. **Group 6B**. Rated for an NEW of 0.5545 pounds TNT equivalent. Contains all fragmentation and provides K24 protection at 1-foot from the shield.

C6.3.1.7. **Prototype 81mm Shield**. Rated for an NEW of 6.72 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 3 feet from the shield.

C6.3.1.8. **Milan 81mm Suppressive Shield**. This is an adaptation of the Prototype 81mm Shield and is rated for an NEW of 4.2 pounds C-4 explosives. Contains all fragmentation and provides K24 protection at 7.3 feet from the shield.

C6.4. **UNEXPLODED ORDNANCE (UXO) DEMOLITION CONTAINER**. Structures that contain all effects (blast and fragments) produced by the intentional detonation of UXO have been designed for use in locations where open detonation may not be an acceptable or desired method of disposal. Such situations can exist as a result of the proximity of exposed persons or property or where transportation of UXO to remote sites may be hazardous, impractical, or economically not feasible. The following containers have been approved by the DDESB:

C6.4.1. **On-site Demolition Container (ODC)**. The COE, Huntsville Division, has designed the ODC for the containment of fragments and overpressure produced by the detonation of UXO up to 81mm in diameter. The maximum explosives weight is 6 pounds of TNT equivalent explosives. The ODC is a cylindrical steel container that is mounted on an integral support frame and working platform. Inside the container, an innovative system of different materials is used to capture fragments. The system includes a layer of sand surrounding the ordnance item to be destroyed, a set of steel cable blasting mats, and a segmented inner steel liner. Water bags, at a ratio of five pounds of water for each pound of TNT equivalent explosives, are used to reduce quasistatic pressures. Water bags, sand, and their containers need to be replaced after every shot. The mats are good for eight to ten shots, while the liner is good for 30 or more shots before they have to be replaced. Reference 6-31 provides information regarding the ODC and how to obtain safety approval for its use. DDESB-KO Memorandum of 15 September 1998 approved use of the ODC and is included as part of reference 6-31. During a detonation, the minimum withdrawal distance for related personnel is 75 feet. The minimum withdrawal for unrelated personnel and the public is the applicable IBD associated with the ordnance item being destroyed. This distance is specified because of hazards associated with operations leading up to an intentional detonation in the container.

C6.4.2. **Full Containment Detonation Chambers/Vessels**.

C6.4.2.1. T-10 Transportable .

C6.4.2.1.1. Reference 6-32 documents the patented T-10 transportable Blast Chamber (DBC), which is capable of containing all pressures and fragmentation resulting from the detonation of UXO up to 81mm in diameter. Demil International, based out of Huntsville, AL, designed the DBC. DDESB-KO Memorandum of 31 January 2000 approved the use of the DBC and is included in reference 6-32. The maximum explosives charge (donor weight and NEW of the projectile) approved for the DBC is 10 pounds HMX (13 pounds TNT equivalency). A round with a diameter no greater than 81mm can be destroyed within the DBC provided its fragment hazard has been determined and falls within specific parameters (i.e., mass, velocity) to ensure that it will not penetrate the chamber walls. The T-10 chamber was not approved for chemical, biological, white phosphorus (WP), or plasticized WP munitions. The following information is provided about the design of a T-10 DBC:

C6.4.2.1.2. The DBC design consists of a box within a box. The void between these boxes is filled with silica sand to dampen and absorb detonation shock. The detonation chamber is lined with replaceable 12-inch X 12-inch X 0.5-inch thick armor plates that are used to stop fragments and to mitigate damage to the interior walls of the detonation chamber. Water bags are suspended inside the chamber to reduce temperatures. The design of the DBC permits the chamber to be used repeatedly. The noise level produced by the detonation of 10 pounds of HMX inside the DBC measures approximately 130 dB at a distance of 30 feet from the DBC. Related personnel are considered to meet all criteria of reference 6-1 when located at a distance of 18 feet from the DBC during detonation operations. However, hearing protection is still required at this distance. The minimum withdrawal for unrelated personnel and the public is the applicable IBD associated with the ordnance item being destroyed. This distance is specified because of hazards associated with operations leading up to an intentional detonation in the container.

C6.4.2.1.2.1. Following an internal detonation, blast pressures, along with detonation byproducts, are vented into a hardened expansion chamber and then through the Air Pollution Control Unit (APCU), where the air-stream is cleaned prior to venting to the environment.

C6.4.2.1.2.2. In March 2002, an amendment requested by the Defense Ammunition Center (DAC) was approved (DDESB-KT Memo of 2 July 2002, Subject: “Amendment to Explosives Safety Submission (ESS) for a Commercially Developed Portable Contained Detonation Chamber (Donovan T -1 0))”. The amendment allows the use of the T-10 for detonation of fragmenting munitions with diameters up to and including 105 mm, provided a minimum of .75-inch thick armor plating is installed on the interior of the T-10 detonation chamber. The maximum NEW remains unchanged at 10 lbs HMX (13 lbs TNT equivalency).

C6.4.2.1.2.3. A second amendment requested by DAC was also approved (DDESB-KT memo of 10 October 2002, Subject: “Amendment 1, 28 February 2002, as Revised 5 June 2002, to Approved Explosives Safety Submission (ESS) for a Commercially Developed Portable Contained Detonation Chamber for Unexploded Ordnance,” 30 November 1999. This amendment permits use of the T-10 for destruction of WP-filled munitions with diameters of 8 1 mm or less. In order to ensure destruction of the WP, the ratio of donor charge (in TNT equivalent weight) to WP is required to be a minimum of 3 to 1, subject to the maximum TNT equivalent explosives limit of 13 lbs. Destruction of munitions containing plasticized WP is currently not permitted.

C6.4.2.2. T-25, T-30 and T-60 Transportable Controlled Detonation Chamber.

C6.4.2.2.1. Built along the same concept as described above for the T-10, DDESB-PD Memorandum of 3 July 2008, Subject: "Explosives Safety/ Protective Design Review of Transportable Controlled Detonation Chamber-Models T-25, T-30 and T-60," approved the use of those chambers for contained intentional detonations with limitations/conditions and with the explosives limits shown below in table 6-1. General siting approval was granted for the disposal of conventional warfare material (not including plasticized white phosphorus (PWP) filled munitions. Minimum donor explosive weight shall be 1 part donor explosive to 1 part energetic fill (1:1) for a munition with energetic fill only; 2:1 for propellant fills; and 3:1 for smoke, riot agent or incendiary fills. Refer to the DDESB for additional conditions/limitations/restrictions.

| CDC | T-25 | T-30 | T-60 |
|---|---|---|---|
| NEW Limit (pounds - TNT equivalent)[1] | 16.7[2] | 40 | 40 |
| Maximum Allowable Diameter (Primary Fragmentation Hazard)[3] | 4.2-in mortar or 4.5-in rocket | 155 mm projectile | 155 mm projectile |

**Notes**:
1. Munition NEWs shall be calculated using the approach provided in Tables 3-2 and 3-3 (and associated notes) of reference (b).
2. Reference (a) requested an explosives limit of 23 pounds TNT Equivalency for the T25 CDC. The T-25 CDC has been tested for 22.7 pounds of PETN sheet explosive, which has different TNT equivalency values for shock and gas pressure. Since the TNT equivalency for gas pressure is lower, the NEW limit is based upon this value. Based upon the chamber's free volume and a 1.25 safety factor, the TNT equivalent gas pressure weight from BLASTX is 16.7 pounds NEW and this has been established as the rated NEW limit. Agreement to reduce NEW limit is found in Army/CH2M Hill responses to DDESB-PD questions (see reference (c)).
3. There is no limit on the number of rounds that can be simultaneously destroyed, subject to the NEW limitation stated in the table above, and provided detonations are conducted as described in paragraph 1.e. below.

Table 6-1: **T-25, T-30, and T-60 CDC Maximum Allowable NEW**

C6.4.2.2.2. The T-60 was also approved by the DDESB for use at Schofield Barracks, HI, for the destruction of chemical munitions. This was a site specific approval, with a maximum TNT equivalent NEW for intentional detonation of 40 lbs, including both the donor and acceptor, as given in Table 6-1 above. The TC-60 that was used was provided with a large-scale filtration system that was capable of absorbing any toxic vapor that might be emitted from detonation operations. The first bank of the filtration system was required to be monitored for the toxic chemical agent of concern and was required to be changed out at the first confirmed breakthrough. Additional conditions/limitations can be found in the DDESB approval memo for the siting of the T60 and its associated process at Schofield Barracks.

C6.4.2.3. The Explosive Destruction System (EDS) is a trailer-mounted mobile system used to destroy explosively configured chemical munitions that are deemed unsafe to transport and fully contain all effects. The system has been used to destroy chemical munitions with or without explosive components. At the heart of the EDS system is an explosion containment vessel and there are 2 phases. EDS, Phase 1 (P1) was approved by DDESB memorandum of 19 April 2005, Subject: "Request for Approval to Increase the Explosive Limit of the Explosive Destruction

System (EDS), Phase 1 Units, in Destruction of Recovered Chemical Warfare Materiel (RCWM)," for up to 1.5 pounds TNT equivalent material. EDS Phase 2 (EDS-P2) design was approved for use by DDESB Memorandum of 9 May 2005, Subject: "Request for Approval of the Explosive Destruction System (EDS), Phase 2 Units, for Use as Specialized Equipment Hardware for Destruction of Recovered Chemical Warfare Materiel (RCWM)," for up to 4.8 pounds of TNT equivalent material (and no greater than 155mm diameter). Any phase 1 or phase 2 unit is approved to handle any chemical agent (except VX) up to the maximum allowable NEW. The EDS uses explosive linear shaped charges to access the agent cavity and to destroy any energetics in the munition. After detonation of the shaped charges, reagents appropriate to the agent to be neutralized are pumped into the vessel and the vessel contents are mixed until the treatment goal has been attained. After the concentration of chemical agent falls below the treatment goal, as determined by sampling the contents of the chamber, the liquid waste solution is transferred out of the chamber into a waste drum. The drummed EDS liquid waste is normally treated further at a commercial hazardous waste treatment, storage, and disposal facility. In addition, a 19 May 2006 DDESB memorandum approved the disposal in the EDS-P2 of a complete, assembled German Traktor Rocket with a chemical projectile on the basis that the propellant would not contribute to the NEW reaction.

## C6.5. NAVY MISSILE TEST CELLS (MTC).

C6.5.1. In 1986, the Naval Civil Engineering Laboratory (NCEL), now known as NFESC, was funded by Naval Ship Weapon Systems Engineering Station to develop NAVFAC Standards for Navy MTC. It was envisioned that there would be six types of MTC as described in Table 1-1 of reference 6-33. These were as follows:

C6.5.1.1. Type I and II (40' L x 25' W x 15' H) with a 300 lbs TNT rated capacity.

C6.5.1.2. Type III (20' L x 15' W x 15' H) with a 105 lb TNT rated capacity.

C6.5.1.3. Type IV (30' L x 20' W x 8' H) with a 1,231 lb TNT rated capacity.

C6.5.1.4. Type 5 (10' L X 10' W X 10' H) with a 40 lb TNT rated capacity.

C6.5.1.5. Type 6 (6' L X 6' W X 8' H) with a 10 lb TNT rated capacity.

C6.5.2. The MTC is a component of an Intermediate Level Maintenance Facility (ILMF), which has the capability to assemble missiles from new or fleet-return sections, test missile all-up-rounds (AURs) or sections, and handle, store, or ship AURs or sections in support of Fleet requirements. The missile is tested in the MTC to certify its performance and reliability before delivery to the Fleet. The test simulates the actual flight and intercept capabilities of the missile. The test missile is an AUR, which includes the rocket motor, guidance and control sections, warhead, and arming device. The test is remotely controlled by personnel and equipment located outside the MTC in a test control room.

C6.5.3. Certain operations, such as an AUR test described above, are considered high risk. The MTC must be designed to protect assets and personnel from either inadvertent ignition of the rocket motor or inadvertent detonation of the warhead. Mitigation of these hazards is performed through protective construction. Each MTC Type is designed to contain/limit the explosion effects associated with specific weapons/items.

C6.5.4. Each MTC is a rectangular-shaped, reinforced concrete structure with a covered passageway leading to the main part of the Missile Processing Building (MPB) and a barricaded area at the opposite end. The barricade is located outside the building and is designed to stop fragments and debris existing the MTC. The end of the MTC facing the barricade is provided a frangible panel for the venting of explosion byproducts. A typical MPB may have several MTC nested side-by-side along one or two faces of the building. Two MTC are usually dedicated to each variant of the missile. This eliminates the need to change test equipment each time a different variant of the missile is tested. It also increases the production rate by allowing a test to be underway in one MTC while another missile is being set up for test in an adjacent MTC. The following MTC have been approved to date:

C6.5.4.1. Type 1: Designed to NCEL Basis of Design (BOD) N-1752R of June 1988 (reference 6-33). The BOD is used by the Architect and Engineering contractor to guide development of MTC construction drawings and specifications. The BOD specifies that construction drawings, specifications, and design calculations be submitted to NFESC (Code 62) for their review to ensure compliance with the requirements of the BOD. The drawings, specifications, and calculations shall be submitted for 35 and 100% design reviews. The maximum NEW for the Type I MTC is 300 lbs TNT or equivalent NEW. Refer to reference 6-34 for the weapon types that can be accommodated in the Type I MTC. The Basis of Design was approved by the DDESB on 7 Dec 1988, and a number of MTC have since been constructed.

C6.5.4.2. Type II: Designed per BOD for NAVFAC Type II Missile Test Cell developed by NCEL (reference 6-34). The maximum NEW is 300 lbs TNT or equivalent NEW. Refer to reference 6-34 for the weapon types that the Type II MTC can accommodate. The BOD was approved by the DDESB on 7 Dec 1988.

C6.6. **SUBSTANTIAL DIVIDING WALLS (SDW).** As an extension of the efforts described in C2.3.14 for the HPM's NPW, there was an interest in finding out if SD criteria, which are based on allowable energy and impulse loads on acceptor munitions, could be applied to SDW. Substantial Dividing Walls are 12-inch thick reinforced concrete (RC) walls meeting certain construction requirements that have been is use since the 1960s for the prevention of prompt propagation between explosives stacks. To answer these questions and expand NPW criteria for SDW use, a series of three tests were conducted between August 2000 and November 2001 by NFESC. The objectives for these tests were to determine SD criteria for SDW and to develop a methodology to design homogeneous RC NPW. Additionally, there was a need to complete additional testing to further refine NPW criteria for NEW in the range of 500 lbs to 3,000 lbs. References 6-35 and 6-36 document the results of the three tests that were conducted and which are described below:

C6.6.1. Test 1 (August 2000) was conducted in a small 4-wall (16' L x 12' W x 12' H) cubicle using 12-inch thick RC gravity walls, with the donor NEW being 425 lbs (440 lbs TNT equivalent explosives) with acceptors being a MK 82 bomb (SG1: selected so that MK82 response could be compared with previous flyer plate test results and finite element analysis), a CBU-87 (SG4), and a M864 Projectile (SG4). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptors being thrown against an adjacent wall. A minimum 3-foot standoff was applied between the donor and specific walls and the floor. This equates to a scaled standoff distance < 1.0 ft/lb$^{1/3}$. The goal of Test 1 was to evaluate response of CBU ammunition to debris impact from local breaching wall response. Calculated velocities of wall fragment ranged from 300 to 500 ft/sec. The results of this test were favorable. There were no reactions of the acceptor munitions, though there was severe deformation of the CBU-87. All submunitions from the CBU-87 were recovered.

C6.6.2. Test 2 (September 2001) was conducted in a larger 4-wall (24' L x 13' 6" W x 8' H) cubicle assembled with various, lightweight (100 pcf) and normal-weight (150 pcf), 24-inch thick reinforced concrete gravity walls. The donor in this test was 3,000 lbs NEW and the acceptors included MK 82 bombs (SG1), M864 projectiles (SG4), and TOW warheads (SG5). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptors being thrown against an adjacent wall. The goal of Test 2 was to obtain acceptor responses to two debris types: breached wall, high velocity, small debris; and unbreached, sheared wall, low velocity, large debris. Test results were favorable. There was no reaction of the MK 82 or M864 projectiles, though there were minor deformations of the M864 projectiles, and all submunitions were recovered. There were low-order reaction (no detonations) of TOW II warheads. One MK 82 (opposite lightweight concrete wall) experienced severe deformation and cracking.

C6.6.3. Test 3 (November 2001) was conducted in a small 4-wall cubicle using 12-inch thick reinforced concrete gravity walls, with the donor NEW being 440 lbs with acceptors being MK 82 Bombs (SG1), M864 Projectile (SG4), CBU-87 (SG4), and TOW II (SG5). Heavy concrete walls were placed behind the acceptor weapons to simulate the acceptor being thrown against an adjacent wall. A minimum 3-foot standoff was applied between the donor and all walls and the floor. This equated to a scaled standoff distance < 1.0 ft/lb$^{1/3}$. The goal of Test 3 was to extend SD criteria for SDW to include SG5 acceptors and observe acceptor responses to debris hazards from localized breaching of wall (high velocity, low mass) and direct shear failure at supports (low velocity, high mass). Calculated velocities of wall fragments ranged from 100 to 500 ft/sec. The results of this test were favorable. There were no reactions of any of the acceptor munitions. The CBU-87 experienced minor deformation of the M864 projectile, and all its submunitions were recovered. The TOW II warheads did not react.

C6.6.4. **<u>TEST RESULTS.</u>** The three tests described above demonstrated that SDW and large dividing walls can prevent SD of acceptor ordnance if HPM SD criteria for unit impulse and energy and wall velocity are satisfied. Also, SD criteria developed for HPM walls apply to designs of conventional (145 pcf) homogeneous reinforced concrete NPW for NEW < 3000 lb. Current SDW wall design criteria and operational constraints are sufficient to prevent SD to SG1, SG2, SG3, and SG4 acceptors, though SG5 acceptors must meet NPW SD criteria (by mitigating loads; for example, by using greater than 3’ donor standoff). Reference 6-37 pulls all known information related to design and use of an NPW for the prevention of prompt propagation together into a single document. Additional work that should be accomplished is also identified and hopefully at some point in the future, this work will be accomplished. It’s important to note that the DDESB has not approved reference 6-36, however the background information and the identified limitations and conditions for use of the information it does contain is important to be aware of.

C6.6.5. **DDESB SDW Criteria**. DDESB-KT Memorandum of 14 May 2001 provided initial guidance regarding the application of and criteria for SDW for the prevention of prompt detonation reactions or propagation of burning reactions (involving AE) between adjacent bays and to provide personnel protection from remotely controlled operations. There was no intent to determine the capability of an SDW to provide intraline protection to personnel. Since this initial guidance was issued, NFESC completed the test series described above and additional analyses, which further increased our knowledge of SDW protection capabilities. The results of those tests and analyses indicated a need to further clarify and define SDW criteria from that provided by the initial guidance. Accordingly, additional controls were identified to limit use of SDW only to those conditions addressed by testing and analysis, and these were incorporated into revised SDW guidance that is addressed in reference 6-38. Additional work is ongoing which will necessitate further revised guidance in the near future, to include the development of a DDESB TP to document the methodology that is used by NFESC to determine the protection capability of an SDW.

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# C7. CHAPTER 7

## BARRICADED MODULE STORAGE

C7.1. **HISTORY**. The following information was extracted from reference 7-1, the Air Force's High Explosives Storage (Big Papa) Test Series Report.

C7.1.1. In July 1966 CINCPACAF informed the Chief of Staff, USAF, of problems encountered in stockpiling required munitions (bombs) at Southeast Asia air bases in compliance with existing explosives quantity-distance criteria. The problem was caused by the shortage of land upon which the bombs could be stored. Explosives safety criteria required that the separation distance (in feet) between aboveground barricaded storage facilities containing mass-detonating explosives be $6W^{1/3}$, and real estate was not available to accommodate these separation distances for the quantities of explosives in theater. The Explosive Safety Branch of the Directorate of Aerospace Safety, HQ USAF, Norton Air Force Base, California, was therefore directed to investigate this critical explosives storage problem. A three-step plan was established. The first step taken was to establish an eight-member USAF Special Study Group (AFSSG), augmented by personnel from the ASESB and BRL, to research and analyze data on both accidental and planned explosions of large quantities of high explosives and to determine if existing QD criteria could be reduced. The AFSSG expended considerable effort searching for data and evidence, which would identify those parameters pertinent to the propagation of sympathetic simultaneous detonations of adjacent barricaded bomb stacks. They found that very little planned experimentation, which was pertinent to the problem at hand, had been accomplished. They also determined that high-speed fragments impinging on adjacent stacks of bombs would be the most likely cause of sympathetic simultaneous detonations from one bomb stack to another and that barricades would be necessary to stop these fragments if any reductions in separation distances were to be possible.

C7.1.2. The AFSSG made a number of recommendations, which are listed below, to the USAF Chief of Staff. The Vice-Chief of Staff, USAF approved the recommendations on 27 September 1966, for immediate use in combat zones.

C7.1.2.1. A modular concept of munitions storage should be utilized. A module was defined as a barricaded area containing a maximum of five cells separated from one another by an intermediate barricade.

C7.1.2.2. The NEW within each cell could not exceed 100,000 pounds. The distance between the nearest edge of the stacks of bombs in adjacent cells would be a minimum of 50 feet. These distance and weight criteria were based on a K factor of 1.1.

C7.1.2.3. The distance between the nearest edge of stacks of bombs in adjacent modules could not be less than 200 feet. This value was based on a K factor of 2.5 applied to the total NEW content of the module.

C7.1.3. The AFSSG also recommended that a test program be conducted to develop minimum separation distances between single stacks of bombs in the 125,000 - to 500,000-pound range, as it was foreseen that the storage of 100,000 pounds per cell would only temporarily alleviate the storage problem being experienced at the time. Conduct of this test program, Explosive Storage (Big Papa) Test Series, was approved by the Air Force Chief of Staff on 28 March 1967 and was directed to proceed as soon as ordnance was available.

C7.2. **EXPLOSIVES STORAGE (BIG PAPA) TEST SERIES**.

C7.2.1. The proposed testing was basically required to determine minimum separation distances between single barricaded aboveground stacks of bombs in the 125,000- to 500,000-pound range and optimum barricade geometry and materials to be used in an explosives storage area. Secondly, testing was required to validate the 100,000-pound modular concept, which had been approved for use in combat zones, and also to investigate the possibility of using this concept universally. It was agreed to by representatives from the Air Force, ASESB, COE, BRL, and NOTS that tests should represent standard barricaded field storage conditions for tritonal-loaded bombs (such as the 750-pound M117), with at least six "samples" of acceptors located at the same separation formula distance of the approved five-cell module (K1.1), or less, from donors containing 250,000 pounds of explosives. Additionally, one of the Air Force representatives proposed a barricade comparison test be conducted and agreed to provide complete details for constructing a test array of six barricades around a donor of 100,000 pounds of explosives.

C7.2.2. **Test Objectives**. The primary objectives of the Big Papa Test Series, conducted between 1 June and 15 October 1967, at Hill Air Force Test Range, UT, were as follows:

C.7.2.2.1. Determine the minimum distance needed between single stacks of barricaded mass-detonating explosives to prevent simultaneous detonation of adjacent stacks and to minimize non-simultaneous propagation.

C7.2.2.2. Determine the validity of the criteria being used in the 100,000-pound NEW cell (five cells per module), approved for combat zone use by the Vice Chief of Staff, USAF, on 27 September 1966.

C7.2.2.3. Determine if the detonation of a single general-purpose bomb, with current explosives fill, within a stack would hurl other bombs into the air above the barricade and subsequently detonate the bombs suspended in the air, resulting in the detonation of adjacent bomb stacks by fragment impingement.

C7.2.2.4. A secondary test objective was to obtain a substantial amount of airblast and ground-shock data for use in future Air Force Weapons Laboratory (AFWL) QD studies.

C7.2.3. **Test Phases**. Testing was divided into four separate phases.

C7.2.3.1. Phases I and II were designed to demonstrate the feasibility of reducing existing, barricaded intermagazine distance criteria to the maximum practical extent for barricaded bomb storage in single stacks in the range of 125,000 to 500,000 pounds NEW of high explosives. Phases I and II were also designed to validate the five-cell module concept, which had been approved for use in combat zones.

C7.2.3.2. Phase III of this test series was designed to determine optimum barricade geometry and materials for use in munitions storage, by comparing the fragment attenuating effectiveness of six different barricades. Four vertical-faced metal-bin barricades, a soil-cement barricade, and a standard earth barricade were tested. A secondary objective of this portion of the test was to obtain a multipurpose barricade, which could be used for aircraft protection, munitions storage, and for protection of habitable buildings. At that period in time, metal-bin barricades were not being used in combat zones for the storage of large quantities of mass-detonating explosives,

C7.2.3.3. Phase IV was an attempt to determine what would happen when only one bomb in an 80-bomb donor stack was detonated. Two acceptors were placed with centerlines 80 feet from the center of a donor. A standard earth barricade separated the donor from the acceptors.

C7.2.4. **Test Conclusions**. Test conclusions were as follows:

C7.2.4.1. A substantial reduction can be made in the then current Department of Defense (DoD) barricaded, aboveground IMD criteria for mass-detonating explosives in open storage (revetments without structures that would burn or create heavy falling weights or damaging secondary fragments).

C7.2.4.2. Bombs located at K = 1.1, or less, from the donor explosions will be covered with earth and unavailable for use until extensive uncovering operations are completed. Bombs at K = 2.5 separations will be readily accessible.

C7.2.4.3. The minimum barricaded distance between single stacks of mass-detonating explosives stored in adjacent cells of a module could be based on a K factor of 1.1 with a high degree of confidence since six stacks, located at distances of K = 1.1 or less (four at 1.1 and one each at 0.9 and 0.8), were tested without causing any sympathetic simultaneous or delayed detonations. However, some possibility of non-simultaneous propagation exists under some circumstances. Dunnage flammability and some possibility of damaging fragments escaping over the barricade are a few of the factors influencing probabilities in this connection.

C7.2.4.4. The modular concept, developed by the AFSSG and approved for use in combat zones, is sound for large-quantity munitions storage.

C7.2.4.5. Since no sympathetic simultaneous or delayed detonations occurred within the test modules, the spacing between modules could be based on a K factor of 2.5 as related to the net weight of explosives in one cell rather than the K2.5 based upon the entire module, as the AFSSG recommendation specified.

C7.2.4.6. The AFSSG recommendation of 100,000 pounds per cell could be increased to 250,000 pounds NEW, provided that the spacing corresponding to a K factor of 1.1 was maintained.

C7.2.4.7. Since no sympathetic simultaneous or delayed detonations occurred, the number of cells per module (five recommended by the AFSSG) was determined to be arbitrary.

C7.2.4.8. The vertical acceleration delivered to a bomb stack resting on the natural ground surface was about twice the magnitude of one standing on a concrete storage pad.

C7.2.4.9. The frontal air pressure was consistently higher than the ground surface pressure at any given distance out from the detonation.

C7.2.4.10. The standard earth barricade does, in fact, affect the airblast in the immediate vicinity of the barricade, but the disturbance dissipates rapidly as the blast front moves out from the detonation. The pressure at a given point on the ground beyond the toe of the barricade was the same as to be expected where no barricades were employed.

C7.2.4.11. Since very few fragments of significance were found out to the barricaded highway/railway distance, most damage to structures would probably result from airblast effects.

C7.2.4.12. The Air Force "2-degree" theory for proper barricade height was determined to be sound.

C7.2.4.13. The standard earth barricade provides excellent fragmentation protection for adjacent bomb stacks stored within a module, as was the case in Phases I and II of the test series.

C7.2.4.14. Cell-to-cell propagation purely by airblast probably will not occur.

C7.2.4.15. Metal-bin barricades having many small parts should not be considered for the storage of large quantities of high explosives, because of the production of secondary fragments (barricade components). The secondary fragments, which had sufficient mass, would be hazardous in an explosives storage area.

C7.2.4.16. The use of steel beams or pilings as anchoring devices for the metal-bin barricades will create hazards in an explosive storage area, in the event of an explosion.

C7.2.4.17. Foam concrete, used as a fragment-catching mechanism to obtain energy data, did not function as designed since no fragment penetrations were detected in any of the 10 acceptors. However, the crater that enveloped the front faces of the acceptors precluded analysis of that portion.

C7.2.4.18. Based on acceleration data, the standard earth barricade remained in position longer and thus performed the fragment-catching function longer than any of the other five barricades tested.

C7.2.4.19. The "high-order" detonation of a single bomb loaded with tritonal or an equivalent fill, within a stack, can be expected to cause the "simultaneous detonation" (practically instantaneous) of all bombs in the stack.

C7.2.4.20. Stacks of bombs spaced at a K-factor distance of 1.1 will require considerable recovery effort if one of the stacks detonates, whereas stacks spaced at a K-factor distance of 2.5 would require very little recovery effort.

C7.2.5. **Post-Test Actions**.

C7.2.5.1. Following the test series, the Air Force contacted the ASESB to inform them of the test results and to describe the proposed recommendations that would be made to the Air Staff. An opinion on these recommendations was requested from the ASESB. A 31 October 1967 ASESB letter documented the conversation. This letter stated that, based on the results of testing, recommendations appeared reasonable, however, an opinion could not be offered by the ASESB until the results of the testing and the recommendations were received in writing.

C7.2.5.2. A 7 December 1967 ASESB letter, written following review of Interim Change 1 to Air Force Manual (AFM) 127-100, which would permit the application of barricaded modules, identifies concerns the ASESB had with the proposed AF use of barricaded modules. In general, the concerns dealt with a perception that AF planners were moving towards application of barricaded module criteria for situations other than operational theaters and for more types of munitions than just those tested in "Big Papa" and that unwarranted capability would be attributed to the "Big Papa" type storage revetments. The last concern had to do with the fact that a detonation in one of the barricaded cells would not protect the serviceability of other munitions in the same module. With respect to using barricaded modules for other than conventional bombs (or munitions of similar mass-detonating characteristics as bombs), plans to store other munitions that had not been tested could result in simultaneous propagation between cells as a result of having materials of a more sensitive nature. At this point, the ASESB had not yet received the test report and had never formally had the opportunity to review the barricaded module concept.

C7.2.5.3. The AF module concept was placed on the agenda (Item 3i.) for the 257th ASESB meeting that was held 10 March 1970. During this meeting, the Board reviewed the Air Force module concept, siting criteria, and utilization and voted to incorporate this concept into DoD Manual 4145.27M, titled DoD Ammunition and Explosives Safety Standards, as a standard in connection with bombs and other cased Class 7 (current designation is Class 1.1) munitions and to undertake a series of tests to determine the applicability of this concept to other type munitions. A summary of the 257th Meeting of the ASESB is provided by ASESB Memorandum of 31 March 1970.

C7.2.5.4. Barricaded module criteria never appear to have made it into 4145.27M. However, these criteria were placed in DoD 5154.4S (the predecessor of DoD 6055.09-STD), dated July 1974, which superceded 4145.27M, dated March 1969.

C7.2.5.5. CBU testing was completed by in September 1972 and recommendations were made to the DDESB for the placement of CBUs in barricaded modules. A 31 October 1972 DDESB-PP letter concurred with the AF's recommendation that mass-detonating CBUs be stored using the same criteria as Class 7 bombs. Subsequent to this DDESB approval, DoD criteria for use of barricaded modules was revised in DoD 5154.4S, (July 1974 version), which stated "The items, which may be stored in modules, are limited to high explosives bombs, similarly cased Class 7 ammunition, and CBUs in authorized, non-flammable shipping containers."

C7.2.5.6. The DDESB approved the AF's request to change module storage criteria as follows:

"The items which may be stored in modules are limited to high explosive bombs, similarly cased Class 1 Division 1 ammunition, CBUs in authorized non-flammable shipping containers, and 20/30mm ammunition in metal shipping containers."

C7.2.5.7. The decision for the inclusion of 20/30mm ammunition in metal shipping containers was based on the similarity of response to CBU munitions. The non-propagating classification and the metal shipping containers assure that the 20/30mm ammunition will not propagate from cell to cell in a module; therefore, module criteria are adequate to limit the effects of a mishap to a single cell.

## C7.3. **<u>REFERENCES</u>**

7-1. Peterson, H., Lemont, C. J. (Capt., USAF), Vergnolle, R. R. (Lt., USAF), "High Explosive Storage Test, Big Papa," Air Force Weapons Laboratory, Technical Report AFWL-TR-67-132, May 1968.

# C8. CHAPTER 8

## AIRFIELD ASSOCIATED PROTECTIVE CONSTRUCTION/MITIGATION

C8.1. **HARDENED AIRCRAFT SHELTERS (HAS) DEVELOPMENT**. This historical information was extracted from references 8-1 through 8-4. In the early 1960s, the AF began an intensive effort to develop a protective arch shelter for tactical aircraft. The impetus for this was the need to protect parked aircraft at Southeast Asia (SEA) installations. Beginning in 1967 with the Concrete Sky test program, the AF began developing and testing various elements of the aircraft shelter in order to optimize the arch and protective cover configuration. A hardened version of the original SEA aircraft shelter was developed as a result of those tests – the TAB VEE hardened aircraft shelter (HAS). This HAS was also known as the 1st Generation (TAB VEE). Later, when NATO specified requirements for hardened shelters for use within the European theater, the TAB VEE HAS design was modified and re-named the 1st Generation (modified TAB VEE). This design was constructed at NATO installations throughout Europe. The results of the Dice Throw Series of high explosives tests (reference 8-3) were used to substantiate the TAB VEE and the Modified TAB VEE designs and to obtain test data to support further HAS structural design improvements. Subsequently, the introduction of newer and larger tactical aircraft, such as the F-111 with its wings fully extended, necessitated modification of the basic 48-foot arch shelter, and the Second (2nd) Generation HAS was developed to accommodate this aircraft. A Third (3rd) Generation HAS was later developed for A-10 or F-15 aircraft, because the 2nd generation HAS was larger than required for those smaller aircraft. By 1977, the AF had 1st (TAB VEE and modified TAB VEE), 2nd, and 3rd Generation HAS in existence, and they are still in use today. These structures are steel-arch, sheet metal structures with a 2-foot sinusoidal wave covered by a minimum of 18 inches of concrete. Concrete cover on the arch itself ranges from 18 to 42 inches thick. The rear wall is constructed of 24-inch thick reinforced concrete with an internal 1/8th-inch thick steel facing. The sliding door is a steel form filled with concrete. There are three basic sizes: 48-foot width (1st Generation), 82-foot width (2nd Generation), and 71-foot width (3rd Generation).

C8.2. **HAS SITING AND TESTING**.

C8.2.1. In 1977, reference 8-4 proposed siting criteria for Group I (1st Generation), II (2nd Generation), and III (3rd Generation) HAS relative to ECM. The proposed criteria were based on the results of the Concrete Sky Phase IXB test of explosive propagation between HAS (reference 8-1) and the 1/3-scale model HAS testing conducted during Dice Throw (reference 8-3). In summary, the Air Force proposal suggested that HAS be sited at IMD distance from ECM, based on their perception that HAS provided the same hardness (protection capability) as a standard ECM. An 18 March 1977 DDESB-KT Memorandum disagreed that the testing showed the HAS designs were completely equivalent to standard ECM. However, the DDESB did agree that the testing showed the HAS designs were capable of providing an increased level of protection. As a result, the DDESB approved HAS exposures to adjacent ECM as follows:

C8.2.1.1. Un-strengthened Group I (1st Generation-TAB VEE) HAS were permitted to be sited side-by-side to one another with no separation distance between them, provided each HAS was limited to one aircraft load containing not more than 4,800 pounds of mass detonating explosives.

C8.2.1.2. The sides of un-strengthened Group I (1st Generation-TAB VEE) HAS were permitted to be oriented toward the side or rear of an ECM at $2.75W^{1/3}$ or toward the front of the ECM at $6W^{1/3}$, provided the ratio of explosives weight to ECM internal volume did not exceed 6 lbs/ft$^3$.

C8.2.1.3. The sides or ends of strengthened Group I (1st Generation-modified TAB VEE) HAS, with strengthened end enclosures, were permitted to be oriented towards the sides or rear of an ECM at $6\ W^{1/3}$ or the front at $5\ W^{1/3}$, provided the ratio of explosives weight to ECM internal volume did not exceed 6 lbs/ft$^3$.

C8.2.1.4. Group II (2nd Generation) and III (3rd Generation) HAS were permitted to be located side-by-side to one another and to Group I (TAB VEE or modified TAB VEE) HAS, with no minimum separation distance between them, provided each HAS was limited to one aircraft load containing not more than 4,800 pounds of mass detonating explosives. For any other application of QD standards, HAS of Group II (2nd Generation) or III (3rd Generation) were to be treated as barricaded, aboveground magazines.

C8.2.2. By 1979, the AF was finding it more and more difficult to site HAS in compliance with then existing explosives safety criteria. Those problems were primarily related to real estate constraints and the AF's operational need to place HAS closer to runways and taxiways. Though a number of HAS-related tests and analyses had been conducted between 1969 and 1977, (reference 8-1 provides a chronology of these), for a number of reasons these tests and analyses only provided limited data capable of supporting further reductions of HAS QD criteria. As a consequence, siting criteria were primarily based on the Concrete Sky Phase IXB Test that was conducted in 1971. That test used a single detonation of 4,632 pounds NEW and a fueled aircraft in an open-ended SEA-type shelter constructed of un-reinforced concrete. By contrast, the HAS constructed in the 1970s were made of reinforced concrete and had reinforced bulkheads and front closure systems. It was felt that these structures were capable of offering more protection, both as explosion sources and as targets, than criteria acknowledged. By closely working with the DDESB, the AF was able to obtain some relief from the then current HAS siting criteria. However, in order to obtain further DDESB-approved QD reductions, additional testing was required. In 1979, the AF initiated the Aircraft Shelter Explosive Test (ASET) Program to develop better QD for HAS.

C8.2.2.1. The overall goals of the ASET Program were to:

C8.2.2.1. Assess the capability of HAS to protect internal assets (aircraft, munitions, and personnel) from external weapons effects (airblast and ground shock).

C8.2.2.2. Assess the capability of HAS to prevent or suppress propagation.

C8.2.2.3. Assess collateral damage effects to and vulnerability of nearby runways and taxiways.

C8.2.2.2. The ASET test program was named DISTANT RUNNER and was separated into two phases. The first phase was to investigate the response of two full-scale 3rd Generation HAS to an external pressure loading, and the second phase was to investigate an internal pressure loading. A total of five tests were conducted and these are described below. Preliminary test analyses, test results, and conclusions are recorded in references 8-5 through 8-11.

C8.2.2.2.1. Event 1 exposed a HAS to an internal detonation of 42 pounds NEW (four Sidewinder (AIM-9) warheads). This weapon arrangement was selected to simulate a weapons load for an aircraft loaded with air-to-air weapons. The primary objective of this test was to demonstrate the ability of a 3rd Generation HAS to completely suppress all effects resulting from an internal detonation involving four AIM-9 missiles.

C8.2.2.2.2. Event 2 exposed both HAS to an external loading of 15 psi produced by the detonation of 240,000 pounds of Ammonium Nitrate/Fuel Oil (ANFO). One of the HAS was oriented side-on to the blast, while the second HAS was oriented rear-on to the blast. Obsolete aircraft were located inside the HAS. The primary objectives of this test were to demonstrate that a 3rd Generation HAS could withstand an external pressure loading of 15 psi in rear-on and side-on orientations to the detonation source, and to demonstrate that a 3rd Generation HAS could prevent internal pressure buildup in these orientations.

C8.2.2.2.3. Event 3 exposed one of the 3rd Generation HAS to an external loading of 15 psi and the other to an external loading of 7.8 psi produced by the detonation of 240,000 pounds of ANFO. The HAS exposed to 15 psi was oriented head-on to the detonation source, while the other HAS was oriented at an oblique angle (26 degrees off normal) to the detonation source. Obsolete aircraft were located inside the HAS. The primary objectives of this test were to demonstrate that a 3rd Generation HAS could withstand external pressure loading of 15 psi in a front-on orientation and 7.8 psi in an oblique orientation to the detonation source and to demonstrate that a 3rd Generation HAS could prevent internal pressure buildup in these orientations.

C8.2.2.2.4. Event 4 exposed a HAS to an internal pressure loading from the detonation of 2,292 pounds NEW (12-MK 82 bombs) inside the HAS. The primary objectives of this test were to demonstrate the blast attenuation characteristics of a 3rd Generation HAS, exposed to an internal detonation involving 2,292 pounds NEW, to evaluate debris distances, and to determine the structure's failure mode.

C8.2.2.2.5. Event 5 exposed a HAS to an internal pressure loading from the detonation of 9,168 pounds NEW (48 MK 82 bombs) inside the HAS. The primary objectives of this test were to demonstrate the blast attenuation characteristics of a 3rd Generation HAS, exposed to an internal detonation involving 9,168 pounds NEW, to evaluate debris distances, and to determine the structure's failure mode.

C8.2.2.2.6. A common secondary objective for Events 2 through 5 was to assess/evaluate the damage (from ground motion effects and fragmentation) to the runway /taxiway as a result of each event.

C8.2.2.3. DISTANT RUNNER results supported the reduction of QD for:

C8.2.2.3.1. Side or rear of an ECM (275,000 pounds NEW TNT) to a 3rd Generation HAS from K30 to K5.

C8.2.2.3.2. Open storage (100,000 pounds NEW TNT) to a 3rd Generation HAS from K30 to K8.

C8.2.2.3.3. ECM (275,000 pounds NEW TNT) to a taxiway/runway from K18 to K4.

C8.2.2.3.4. Open storage (100,000 pounds NEW TNT) to a taxiway/runway from K18 to K4.

C8.2.2.4. DISTANT RUNNER results were unable to support a reduction of QD for HAS to occupied (inhabited) structures, but instead demonstrated a need for increased separation distances. Consequently, increased QD was required as follows:

C8.2.2.4.1. Distance (d) = 50 $W^{1/3}$ from the front of a HAS.

C8.2.2.4.2. D = 62 $W^{1/3}$ from the sides of a HAS.

C8.2.2.4.3. D = 40 $W^{1/3}$ from the rear of a HAS.

C8.2.3. At the 283rd Meeting of the DDESB, which met on 19 January 1982, the AF presented their rationale as to why the separation distances between HAS and ECM, approved previously by the DDESB for 3rd Generation HAS, should apply to all HAS, except the door of a 1st generation HAS. DDESB approval of the proposed AF changes can be found in 1 February 1982 DDESB-IK memorandum. These changes, as well as those previously approved by the DDESB for HAS siting, were published in reference 8-12.

C8.2.4. Additional 3rd Generation HAS siting criteria changes were proposed in 1995. Those changes resulted from U.S. involvement in the NATO AC/258 (Group of Experts on Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) Small Quantities Workshop. The AF subsequently recommended DDESB adoption of these proposed revised third-generation HAS siting criteria, and they were discussed during the 310th Board Meeting; however, they were not put forward as a voting item. The DDESB Secretariat felt that additional analyses and test data were needed before the proposed changes could be presented to the Board as a voting item. Subsequently, based on data presented (references 8-13 through 8-15) at the 26th DoD Explosives Safety Seminar, and based on DDESB Secretariat and DDESTSG review of the proposed changes, the original proposal was revised and then presented to the 311th Board that met on 19 January 1995, for a vote. The Board unanimously approved the modified changes governing siting of third-generation HAS, which permitted reduced QD for a third-generation HAS, for selected ranges of NEW present within the HAS.

C8.2.5. On 3 December 1998, a revised version of Chapter 10 of DoD 6055.09-STD was approved by the Chairman, DDESB, based on previous written endorsement of the revision by Board members. As part of this approval, a statement was to be added to Chapter 9 permitting the use of Chapter 10 HAS criteria to peacetime operations as well as to contingency and combat operations. HAS criteria were subsequently moved into Chapter 9 during the DoD 6055.09-STD Rewrite effort.

## C8.3. <u>SIGNIFICANT ENHANCEMENT OF HAS CRITERIA SINCE 1995</u>

C8.3.1. As a result of numerous issues that were coming up related to the application of HAS criteria, the DDESB, with the assistance of the AFSC, began a significant effort to resolve the issues and develop missing criteria. The major issues were that DoD 6055.09-STD did not:

a. Provide QD criteria for Korean TAB VEE, Korean TAB VEE Modified, or Korean Flow-Through HAS.

b. Provide QD criteria from Storage Area ECM/ AGM to any type of HAS.

c. Provide QD criteria from First Generation, Second Generation, Korean TAB VEE, Korean TAB VEE Modified, or Korean Flow-Through HAS to Unhardened Exposed Sites.

d. Address siting of Hazard Division (HD) 1.2, HD 1.3 or HD 1.4 in a HAS.

C8.3.2. Korean-type HAS are unique HAS found only at U.S. Air Force installations in South Korea. There are three different designs and these are the Korean TAB VEE, a hardened Korean TAB VEE (concrete rear wall with the rear vent opening protected by a steel bin barricade and a first generation front closure), and a Korean flow-thru (no front or rear wall). The arches of those Korean HAS are identical to either the first or third generation HAS arch, thus providing significant blast and fragmentation protection.

C8.3.3. In order to correct this deficiency, DDESB (Eric Deschambault) and Air Force Safety Center (AFSC) representatives (Lea Ann Cotton) began working together, starting in 2003, to develop the lacking HAS criteria. Once completed, it was their intent for the AFSC to submit a proposed change to DoD criteria for review/approval at a future Board meeting. This was accomplished as discussed later in this section.

C8.3.3.1. As an initial step in this process, Eric Deschambault of the DDESB collected historical information about HAS and consolidated it into a “History of the Air Force’s Hardened Aircraft Shelter Program,” 25 January 2007 (reference 8-16).

C8.3.3.2. Using the above reference and all available test data and analysis of that data (e.g., Concrete Sky, Dice Throw, Distant Runner, ASUP) as a basis for the proposed changes, DDESB and AFSC developed specific, supporting rationale for each proposed change to address the deficiencies given above. The supporting rationale and proposed changes, which were closely coordinated with the AFSC, are detailed in the Action 4 Attachment to the DDESB-PD

Memorandum of 21 November 2007, Subj: 331st Department of Defense Explosives Safety Board Meeting. The six parts of the proposed changes were as follows:

a. Change 1 – Revise the current paragraph C9.6.1.5 for HAS to address all types of HAS, and siting of HD 1.2, HD 1.3 and HD 1.4 in HAS.

b. Change 2 – Revise the current Table C9.T25 (HAS K-factors for Propagation Prevention) to address the various Korean HAS.

c. Change 3 – Revise the current Table C9.T26 (HAS K-factors for Asset Preservation) to address the various Korean HAS, and storage area ECM/AGM.

d. Change 4 – Revise the current Table C9.T27 (QD from a Third Generation HAS to Unhardened ES) to address Second Generation HAS and the sides of a Korean Flow-Through HAS.

e. Change 5 – Add a new Table C9.T27A (QD from a First Generation HAS to an Unhardened ES) to address First Generation HAS and the sides/rear of a Korean TAB VEE HAS.

f. Change 6 – Revise and add new HAS definitions.

C8.3.3.3. The 331st DDESB (DDESB-PD Memorandum of 9 January 2008, Subj: 331st Department of Defense Explosives Safety Board Meeting approved the above criteria with one proposed change, which involved updating Table C9.T24 to add a HAS column and HAS row.

C8.3.3.4. Some minor adjustments to the criteria have since been accomplished.

## C8.4 <u>REDUCED QD FOR F-15 AND F-16 AIRCRAFT CONFIGURATIONS INVOLVING AIM 7, AIM 9, AND AIM 120 MISSILES</u>.

C8.4.1. The U.S. Air Force conducted significant missile testing and missile-on-aircraft testing to determine associated MCE and QD for a number of F-15 and F-16 missile configurations. Based on this testing, DDESB-KT Memorandum of 5 May 2004 approved revised MCE and QD for those aircraft configurations listed in Table 8.1. The rationale on which DDESB approval was based is provided as part of reference 8-17.

C8.4.2. Table 8.2 provides the individual missile NEWQD used for determining required aircraft configuration MCE.

C8.4.2.1. **<u>Test Results</u>**.

a. Table 8.3 shows the single missile HFD determined as part of the Air Force Test Program.

b. Tables 8.4 and 8.5 show the MCE for each aircraft configuration from Table 8.1 above. In some cases for the F-15, the configurations are broken down into cases based on missile configurations and/or positions.

C8.4.2.2.2. **Initial Quantity-Distance Determinations for Aircraft in the Open.**

a. Tables 8.6 through 8.12 show the initial Q-D determinations for aircraft in the open.

b. Tables 8.13 and 8.14 show the final Q-D determinations for aircraft in the open. The Q-D presented in these tables are only for the aircraft and missile configurations described in Tables 8.1 and 8.2.

c. The variations presented in Tables 8.6 through 8.12 have been reduced for purposes of simplification. In many instances, only slight differences in NEWQDs and IL distances existed between some variations. The Air Force determined these differences were not significant, and elected to apply the worst-case NEWQD and IL distance.

d. The IM distances presented in Tables 8.6 through 8.12 are superseded by the minimum aircraft separation requirement of 10 ft, per normal flight line criteria. Therefore, the Air Force has elected to use 10 ft as the default IM distance between aircraft in all cases. However, units may request lesser distances (down to those in Tables 8.6 through 8.12) if circumstances require. The Air Force will approve these on a case-by-case basis.

C8.4.2.2.3. **Final Quantity-Distance Determinations for Aircraft in the Open**.

a. Tables 8.13 and 8.14 show the final Q-D determinations for aircraft in the open. The QD presented in these tables are only for the aircraft and missile configurations described in Tables 8.1 and 8.2.

b. The variations presented in Tables 8.6 through 8.12 have been reduced for purposes of simplification. In many instances, only slight differences in NEWQDs and IL distances existed between some variations. The Air Force determined these differences were not significant, and elected to apply the worst-case NEWQD and IL distance.

c. The IM distances presented in Tables 8.6 through 8.12 are superseded by the minimum aircraft separation requirement of 10ft, per normal flightline criteria. Therefore, the Air Force has elected to use 10 ft as the default IM distance between aircraft in all cases. However, units may request lesser distances (down to those in Tables 8.6 through 8.12) if circumstances require. The Air Force will approve these on a case-by-case basis.

C8.4.2.2.4. **Considerations for Aircraft in Buildings**. Table 8.15 applies to aircraft configurations of Tables 8.13 and 8.14 when located in one of the structures shown below. For structures of heavier construction, conduct a structural analysis per reference 1-2 to determine the appropriate debris IB distance to apply.

## Table 8.1. Aircraft Configurations

| F-16 | |
|---|---|
| Configuration 1 | 4 AIM-120 missiles, 2 AIM-9 missiles |
| Configuration 2 | 2 AIM-120 missiles, 2 AIM-9 missiles, 2 AIM-7 missiles |
| Configuration 3 | 2 AIM-120 missiles, 4 AIM-9 missiles |
| Configuration 4 | 6 AIM-120 missiles |
| **F-15** | |
| Configuration 1 | 4 AIM-120 missiles, 2 AIM-9 missiles, 2 AIM-7 missiles |
| Configuration 2 | 4 AIM-9 missiles, 4 AIM 7 missiles |
| Configuration 3 | 6 AIM-120 missiles, 2 AIM-9 missiles |

## Table 8.2. Missile Configurations

| Missile | Missile NEWQD | Basis for Missile NEWQD |
|---|---|---|
| AIM-120, WDU-33/B Warhead | 16.9 lbs | Warhead NEWQD (15 lbs) plus some motor contribution. |
| AIM-120, WDU-41/B Warhead | 19.0 lbs | Warhead NEWQD (16 lbs) plus some motor contribution. |
| AIM-9L,M, and X, WDU-17 Warhead | 7.9 lbs | Warhead NEWQD only. |
| AIM-9P | 10.5 lbs | Warhead NEWQD only. |
| AIM-7M, WAU-17 Warhead | 36.0 lbs | Warhead NEWQD only. |
| AIM-7F, WAU-10 Warhead | 26.1 lbs | Warhead NEWQD only. |

## Table 8.3. Test Results – Single Missile Hazard Fragment Distances

| Missile | Single Missile Hazardous Fragment Distance (HFD) |
|---|---|
| AIM-120, WDU-33/B Warhead | 280 ft |
| AIM-120, WDU-41/B Warhead | 335 ft |
| AIM-9L,M, and X, WDU-17 Warhead | 400 ft |
| AIM-9P, Warhead | 400 ft |
| AIM-7M, WAU-17 Warhead | 280 ft |
| AIM-7F, WAU-10 Warhead | 199 ft |

**Table 8.4. Test Results – F-16 Aircraft Configuration Maximum Credible Events**

| **Configuration** | **Maximum Credible Event (MCE)[1,2]** |
|---|---|
| Configuration 1<br>(4 AIM-120s, 2 AIM-9s) | One AIM-120 and One AIM-9 |
| Configuration 2<br>(2 AIM-120s, 2 AIM-9s, 2 AIM-7s) | One AIM-9 and One AIM-7 |
| Configuration 3<br>(2 AIM-120s, 4 AIM-9s) | One AIM-120 and Two AIM-9s |
| Configuration 4<br>(6 AIM-120s) | One AIM-120 |

Note 1: For each missile type, the missile configuration present with the largest NEWQD would be used for calculation of the NEWQD of the configuration MCE. For example, in Configuration 4, if 3 AIM-120, WDU-33/Bs and 3 AIM-120, WDU-41/Bs were present, the NEWQD for the Maximum Credible Event would be 19 lbs (the NEWQD of one AIM-120, WDU-41/B).

Note 2: HFD is based on the largest HFD of any single missile present.

**Table 8.5. Test Results – F-15 Aircraft Configuration Maximum Credible Events**

| Configuration | Maximum Credible Event (MCE) [1,2] |
|---|---|
| Configuration 1<br>(4 AIM-120s, 2 AIM-9s, 2 AIM-7s) | |
| Case 1 – AIM-7s in Rear<br>Fuselage Position | *Use whichever produces largest NEWQD:*<br>One AIM-7<br>*or* One AIM-120 and One AIM-9 |
| Case 2 – AIM-7s in Front<br>Fuselage Position | One AIM-9 and One AIM-7 |
| Configuration 2<br>(4 AIM-9s, 4 AIM-7s) | |
| Case 1 – AIM-7Ms in Front<br>Fuselage Position,<br>and any AIM-9Ps | Two AIM-9s and One AIM-7 |
| Case 2 – AIM-7Fs in Front<br>Fuselage Position | One AIM-7 |
| Case 3 – Only AIM-7Ms,<br>and only AIM-9Ls or 9Ms | One AIM-7 |
| Configuration 3<br>(6 AIM-120s, 2 AIM-9s) | One AIM-120 and One AIM-9 |

Note 1: For each missile type, the missile configuration present with the largest NEWQD would be used for calculation of the NEWQD of the configuration MCE. For example, in Configuration 2, Case 2, if 2 AIM-7Fs and 2 AIM-7Ms were present, the NEWQD for the Maximum Credible Event would be 36 lbs (the NEWQD of one AIM-7M).

Note 2: HFD is based on the largest HFD of any single missile present.

## Table 8.6. Initial Q-D Determinations for F-16, Configuration 1, in the Open

| Configuration 1 (4 AIM-120s, 2 AIM-9s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| a. Only AIM-120, WDU-33/Bs Only AIM-9Ls, 9Ms, or 9Xs | One AIM-120, WDU-33/B and One AIM-9L/M/X | 24.8 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 53 ft | 100 in |
| b. Any AIM-120, WDU-41/Bs Only AIM-9Ls, 9Ms, or 9Xs | One AIM-120, WDU-41/B and One AIM-9L/M/X | 26.9 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 54 ft | 100 in |
| c. Only AIM-120, WDU-33/Bs Any AIM-9Ps | One AIM-120, WDU-33/B and One AIM-9P | 27.4 lbs | 400 ft (AIM-9P) | 240 ft | 55 ft | 100 in |
| d. Any AIM-120, WDU-41/Bs Any AIM-9Ps | One AIM-120, WDU-41/B and One AIM-9P | 29.5 lbs | 400 ft (AIM-9P) | 240 ft | 56 ft | 100 in |

Note 1: MCE is based on rule from Table 4.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: Assumes AIM-120s are on the wing tips. IM is 36 inches if AIM-9s are on the wing tips (to maintain 100 inches between AIM-120s).

## Table 8.7. Initial Q-D Determinations for F-16, Configuration 2, in the Open

| Configuration 2 (2 AIM-120s, 2 AIM-9s, 2 AIM-7s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| a.1 Only AIM-9Ls, 9Ms, or 9Xs<br>Only AIM-7Fs | One AIM-9L/M/X and One AIM-7F | 34.0 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 59 ft | 100 in |
| a.2 Any AIM-9Ps<br>Only AIM-7Fs | One AIM-9P and One AIM-7F | 36.6 lbs | 400 ft (AIM-9P) | 240 ft | 60 ft | 100 in |
| b.1 Only AIM-9Ls, 9Ms, or 9Xs<br>Any AIM-7Ms | One AIM-9L/M/X and One AIM-7M | 43.9 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 64 ft | 100 in |
| b.2 Any AIM-9Ps<br>Any AIM-7Ms | One AIM-9P and One AIM-7M | 46.5 lbs | 400 ft (AIM-9P) | 240 ft | 65 ft | 100 in |

Note 1: MCE is based on rule from Table 4.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: Assumes AIM-120s are on the wing tips. IM is 36 inches if AIM-9s are on the wing tips (to maintain 100 inches between AIM-120s).

## Table 8.8. Initial Q-D Determinations for F-16, Configuration 3, in the Open

| Configuration 3 (2 AIM-120s, 4 AIM-9s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| a. Only AIM-120, WDU-33/Bs<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs | One AIM-120, WDU-33/B and Two AIM-9L/M/Xs | 32.7 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 58 ft | 100 in |
| b. Any AIM-120, WDU-41/Bs<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs | One AIM-120, WDU-41/B and Two AIM-9L/M/Xs | 34.8 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 59 ft | 100 in |
| c. Only AIM-120, WDU-33/Bs<br>Any AIM-9Ps | One AIM-120, WDU-33/B and Two AIM-9Ps | 37.9 lbs | 400 ft (AIM-9P) | 240 ft | 61 ft | 100 in |
| d. Any AIM-120, WDU-41/Bs<br>Any AIM-9Ps | One AIM-120, WDU-41/B and Two AIM-9Ps | 40.0 lbs | 400 ft (AIM-9P) | 240 ft | 62 ft | 100 in |

Note 1: MCE is based on rule from Table 4.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: Assumes AIM-120s are on the wing tips. IM is 36 inches if AIM-9s are on the wing tips (to maintain 100 inches between AIM-120s).

## Table 8.9. Initial Q-D Determinations for F-16, Configuration 4, in the Open

| Configuration 4 (6 AIM-120s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM |
|---|---|---|---|---|---|---|
| a. Only AIM-120, WDU-33/Bs | One AIM-120, WDU-33/B | 16.9 lbs | 280 ft (AIM-120, WDU-33/B) | 168 ft | 47 ft | 100 in |
| b. Any AIM-120, WDU-41/Bs | One AIM-120, WDU-41/B | 19.0 lbs | 335 ft (AIM-120, WDU-41/B) | 201 ft | 48 ft | 100 in |

Note 1: MCE is based on rule from Table 4.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.

## Table 8.10. Initial Q-D Determinations for F-15, Configuration 1, in the Open

| Configuration 1 (4 AIM-120s, 2 AIM-9s, 2 AIM-7s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| Case 1 – AIM-7s in Rear Fuselage Position | | | | | | |
| a.1 Only AIM-7Fs<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs<br>Only AIM-120, WDU-33/Bs | One AIM-7F | 26.1 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 54 ft | 100 in |
| a.2 Only AIM-7Fs<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs<br>Any AIM-120, WDU-41/Bs | One AIM-120, WDU-41/B and One AIM-9L/M/X | 26.9 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 54 ft | 100 in |
| a.3 Only AIM-7Fs<br>Any AIM-9Ps<br>Only AIM-120, WDU-33/Bs | One AIM-120, WDU-33/B and One AIM-9P | 27.4 lbs | 400 ft (AIM-9P) | 240 ft | 55 ft | 100 in |
| a.4 Only AIM-7Fs<br>Any AIM-9Ps<br>Any AIM-120, WDU-41/Bs | One AIM-120, WDU-41/B and One AIM-9P | 29.5 lbs | 400 ft (AIM-9P) | 240 ft | 56 ft | 100 in |
| b. Only AIM-7Ms | One AIM-7M | 36.0 lbs | 400 ft (AIM-9L/M/X/P) | 240 ft | 60 ft | 100 in |
| Case 2 – AIM-7s in Front Fuselage Position | | | | | | |
| a.1 Only AIM-7Fs<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs | One AIM-7F and One AIM-9L/M/X | 34.0 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 59 ft | 100 in |
| a.2 Only AIM-7Fs<br>Any AIM-9Ps | One AIM-7F and One AIM-9P | 36.6 lbs | 400 ft (AIM-9P) | 240 ft | 60 ft | 100 in |
| b.1 Any AIM-7Ms<br>Only AIM- AIM-9Ls, 9Ms, or 9Xs | One AIM-7M and One AIM-9L/M/X | 43.9 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 64 ft | 100 in |
| b.2 Any AIM-7Ms<br>Any AIM-9Ps | One AIM-7M and One AIM-9P | 46.5 lbs | 400 ft (AIM-9P) | 240 ft | 65 ft | 100 in |

Note 1: MCE is based on rule from Table 5.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: Assumes AIM-120s are on the wing tips. IM is 36 inches if AIM-9s are on the wing tips (to maintain 100 inches between AIM-120s).

## Table 8.11. Initial Q-D Determinations for F-15, Configuration 2, in the Open

| Configuration 2 (4 AIM-9s, 4 AIM-7s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| Case 1 – AIM-7Ms in Front Fuselage Position, Any AIM-9Ps | | | | | | |
| a. AIM-7Fs in Rear | One AIM-7M and Two AIM-9Ps | 57.0 lbs | 400 ft (AIM-9P) | 240 ft | 70 ft | 22 in |
| b. AIM-7Ms in Rear | One AIM-7M and Two AIM-9Ps | 57.0 lbs | 400 ft (AIM-9P) | 240 ft | 70 ft | 22 in |
| Case 2 – AIM-7Fs in Front Fuselage Position, Any AIM-9Ps | | | | | | |
| a. AIM-7Fs in Rear | One AIM-7F | 26.1 lbs | 400 ft (AIM-9P) | 240 ft | 54 ft | 22 in |
| b. AIM-7Ms in Rear | One AIM-7M | 36.0 lbs | 400 ft (AIM-9P) | 240 ft | 60 ft | 22 in |
| Case 3 – Only AIM-7Ms, Only AIM-9Ls, 9Ms, or 9Xs | One AIM-7M | 36.0 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 60 ft | 22 in |

Note 1: MCE is based on rule from Table 5.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: For all cases presented for this configuration, the AIM-9s are on the outer stations and the AIM-7s are on the fuselage. Although the IM between the AIM-9s is 22 inches, the aircraft structure precludes the AIM-9s from being this close.

## Table 8.12. Initial Q-D Determinations for F-15, Configuration 3, in the Open

| Configuration 3 (6 AIM-120s, 2 AIM-9s) | MCE[1] | NEWQD for MCE | HFD/IBD[2] | PTR[3] | IL[4] | IM[5] |
|---|---|---|---|---|---|---|
| a. Only AIM-120, WDU-33/Bs Only AIM-9Ls, 9Ms or 9Xs | One AIM-120, WDU-33/B and One AIM-9L/M/X | 24.8 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 53 ft | 100 in |
| b. Any AIM-120, WDU-41/Bs Only AIM-9Ls, 9Ms or 9Xs | One AIM-120, WDU-41/B and One AIM-9L/M/X | 26.9 lbs | 400 ft (AIM-9L/M/X) | 240 ft | 54 ft | 100 in |
| c. Only AIM-120, WDU-33/Bs Any AIM-9Ps | One AIM-120, WDU-33/B and One AIM-9P | 27.4 lbs | 400 ft (AIM-9P) | 240 ft | 55 ft | 100 in |
| d. Any AIM-120, WDU-41/Bs Any AIM-9Ps | One AIM-120, WDU-41/B and One AIM-9P | 29.5 lbs | 400 ft (AIM-9P) | 240 ft | 56 ft | 100 in |

Note 1: MCE is based on rule from Table 5.
Note 2: HFD is based on the largest HFD of any single missile present. The HFD is also the IBD, because in all cases it exceeds K40 using the NEWQD for MCE.
Note 3: PTR is 60% of IBD.
Note 4: IL is K18, using the NEWQD for MCE.
Note 5: Assumes AIM-120s are on the wing tips. IM is 36 inches if AIM-9s are on the wing tips (to maintain 100 inches between AIM-120s).

## Table 8.13. Q-D for F-16 Aircraft in the Open

| *See Notes 1 and 2* | NEWQD for MCE | HFD/IBD | PTR | IL | IM[3] |
|---|---|---|---|---|---|
| **Configuration 1** 4 AIM-120s, 2 AIM-9s | 29.5 lbs | 400 ft | 240 ft | 56 ft | 10 ft |
| **Configuration 2a** 2 AIM-120s, 2 AIM-9s, 2 AIM-7Fs | 36.6 lbs | 400 ft | 240 ft | 60 ft | 10 ft |
| **Configuration 2b** 2 AIM-120s, 2 AIM-9s, 2 AIM-7Ms | 46.5 lbs | 400 ft | 240 ft | 65 ft | 10 ft |
| **Configuration 3** 2 AIM-120s, 4 AIM-9s | 40.0 lbs | 400 ft | 240 ft | 62 ft | 10 ft |
| **Configuration 4a** 6 AIM-120, WDU-33/Bs | 16.9 lbs | 280 ft | 168 ft | 47 ft | 10 ft |
| **Configuration 4b** 6 AIM-120s, with one or more being an AIM-120, WDU-41/B | 19.0 lbs | 335 ft | 201 ft | 48 ft | 10 ft |

Note 1: Configuration numbers do not correspond to configuration numbers in AFMAN 91-201.
Note 2: Unless otherwise specified,
- AIM-120s must be AIM-120, WDU-33/Bs and/or AIM-120, WDU-41/Bs
- AIM-9s must be AIM-9L, WDU-17s, and/or AIM-9M, WDU-17s, and/or AIM-9X, WDU-17s, and/or AIM-9P
- AIM-7s must be AIM-7M, WAU-17s and/or AIM-7F, WAU-10s

Note 3: This IM is based on the minimum aircraft separation requirement of 10 ft. If circumstances require locating aircraft at less than this distance, then lesser IM distances may be approved by the Air Force.

## Table 8.14. Q-D for F-15 Aircraft in the Open

| *See Notes 1 and 2* | NEWQD for MCE | HFD/IBD | PTR | IL | IM[3] |
|---|---|---|---|---|---|
| **Configuration 1, Case 1a** 4 AIM-120s, 2 AIM-9s, 2 AIM-7Fs in Rear Fuselage Position | 29.5 lbs | 400 ft | 240 ft | 56 ft | 10 ft |
| **Configuration 1, Case 1b** 4 AIM-120s, 2 AIM-9s, 2 AIM-7Ms in Rear Fuselage Position | 36.0 lbs | 400 ft | 240 ft | 60 ft | 10 ft |
| **Configuration 1, Case 2a** 4 AIM-120s, 2 AIM-9s, 2 AIM-7Fs in Front Fuselage Position | 36.6 lbs | 400 ft | 240 ft | 60 ft | 10 ft |
| **Configuration 1, Case 2b** 4 AIM-120s, 2 AIM-9s, 2 AIM-7Ms in Front Fuselage Position | 46.5 lbs | 400 ft | 240 ft | 65 ft | 10 ft |
| **Configuration 2, Case 1** 2 AIM-7Ms in Front Fuselage Position, 2 AIM-7Fs or Ms in Rear Fuselage Position, 4 AIM-9s | 57.0 lbs | 400 ft | 240 ft | 70 ft | 10 ft |
| **Configuration 2, Case 2a** 4 AIM-7Fs, 4 AIM-9s | 26.1 lbs | 400 ft | 240 ft | 54 ft | 10 ft |

## Table 8.14. Q-D for F-15 Aircraft in the Open (Continued)

| *See Notes 1 and 2* | NEWQD for MCE | HFD/IBD | PTR | IL | IM[3] |
|---|---|---|---|---|---|
| **Configuration 2, Case 2b**<br>2 AIM-7Fs in Front Fuselage Position,<br>2 AIM-7Ms in Rear Fuselage Position,<br>4 AIM-9s | 36.0 lbs | 400 ft | 240 ft | 60 ft | 10 ft |
| **Configuration 2, Case 3**<br>4 AIM-7Ms,<br>4 AIM-9Ls or 9Ms | 36.0 lbs | 400 ft | 240 ft | 60 ft | 10 ft |
| **Configuration 3**<br>6 AIM-120s, 2 AIM-9s | 29.5 lbs | 400 ft | 240 ft | 56 ft | 10 ft |

Note 1: Configuration numbers do not correspond to configuration numbers in AFMAN 91-201.
Note 2: Unless otherwise specified,
- AIM-120s must be AIM-120, WDU-33/Bs and/or AIM-120, WDU-41/Bs
- AIM-9s must be AIM-9L, WDU-17s, and/or AIM-9M, WDU-17s, and/or AIM-9X, WDU-17s, and/or AIM-9P, 10.5lb Warheads
- AIM-7s must be AIM-7M, WAU-17s and/or AIM-7F, WAU-10s

Note 3: This IM is based on the minimum aircraft separation requirement of 10 ft. If circumstances require locating aircraft at less than this distance, then lesser IM distances may be approved by the Air Force.

**Table 8.15. Q-D for Table 13 and 14 Aircraft Configurations in Light Structures.**

| | IB | PTR | IL/IM |
|---|---|---|---|
| Fabric/Tubular Shelter or Light Metal Structure | Aircraft Configuration HFD [1] | Note 2 | Note 3 |

Note 1: Minimum debris distance of 279 feet applies when in a light metal structure. No minimum debris distance applies to a fabric/tubular shelter.
Note 2: PTR is 60% of HFD.
Note 3: IL and IM distances are the same as determined for “open” in previous section.

## C8.5. APPROVAL OF REDUCED MAXIMUM CREDIBLE EVENT (MCE) FOR AIM-9 AND AIM-120 MIXED TRAILER CONFIGURATION.

C8.5.1. DDESB-IK Memorandum of 10 February 2004 approved the reduced MCE for mixed storage configurations of two AIM-120 (any model) and two AIM-9 (any model) all-up missiles on an MHU-141/M missile transport trailer. The following conditions apply to this approval for use of a reduced MCE for AIM-9 and AIM-120 missiles on an MHU-141/M missile transport trailer:

a. The two AIM-120 missiles will be loaded only on the inside stations of the trailer, oriented in alternating directions to prevent warheads being located adjacent to each other. Ensure missiles are centered on trailer.

b. The two AIM-9 missiles will be loaded only on the outer stations of the trailer. The direction of the AIM-9s is optional. Ensure missiles are centered on trailer. Line-of-sight between the two AIM-9 missiles must be prevented while on the trailer.

c. The above placement will result in the two AIM-9 missiles (any orientation) being separated by two AIM-120 missiles (oriented in alternating directions).

d. The MCE for a trailer load meeting the above conditions is one AIM-120 missile and one AIM-9 missile, and the maximum allowable NEWQD for the trailer load, based on this MCE, is 29.5 pounds HD 1.1.

e. The QD allowed for the subject trailer are as follows:

IBD - 400 feet;

PTRD - 60% of IBD, which equates to 240 feet;

IL distance - $18*NEWQD^{1/3}$; and

IM distance - 100 inches.

## C8.6. APPROVAL OF MCE FOR MULTIPLE ALL-UP-ROUND (AUR) CONTAINERS OF AIM-7 MISSILES WITH WAU-10 WARHEADS.

C8.6.1. Based on testing results documented in reference 8-18, DDESB-IK Memorandum of 30 September 2004 approved the establishment of the MCE, for stacks of multiple AIM-7 Missile (with WAU-10 Warheads) AUR containers, to be a single AUR container. The following pertain to this approval:

a. All four AIM-7 Missiles within the AUR container must be oriented in the same direction.

b. There are no restrictions on the orientation of AUR containers, relative to each other.

c. The NEWQD associated with an AUR container is 105 pounds HD 1.1. This is determined by using the MCE of a single AIM-7 (with a WAU-10 Warhead) as 26.1 pounds and multiplying it by 4, the number of warheads in an AUR container.

d. The QD associated with the AIM-7 (with WAU-10 Warhead) AUR container will be in accordance with paragraph C9.4.1.2.1.1.1 of DoD 6055.09-STD.

## C8.7. MISSILE CONTAINER STORAGE REDUCED MAXIMUM CREDIBLE EVENT (MCE) FOR AIR-TO-AIR MISSILES

C8.7.1. DDESB-PD Memorandum of 25 April 2008 approved a single container MCE for a mixed storage configuration ofAIM-7, AIM-9 and AIM-120 air-to-air missile containers provided the following conditions are met:

a. Each stack of containers will contain the same type of missile and warhead.

b. Each stack will be no more than three containers high.

c. For containers of AIM-7 missiles with the WAU-10 warhead: (1) the missiles must be oriented in the same direction within the container, (2) there is no restriction on the orientation of the containers relative to one another within a stack, (3) there is no restriction on the orientation of containers between stacks, and (4) there is no required separation between stacks. MCE of the stack(s) is 105 lbs of HD 1.1 (based on the four warheads a single container).

d. For containers of AIM-7 missiles with the WAU·10 warhead: (1) the missiles must be oriented in the same direction within the container, (2) the containers within a single stack must be alternated (nose-to-tail), (3) there is no restriction on the orientation of containers between stacks, and (4) there is no required separation between stacks. MCE of the stack(s) is 144 lbs of HD 1.1 (based on the four warheads in a single container).

e. For containers of AIM-9 missiles with the WDU-l7 warhead: (1) there is no restriction on the orientation of the missiles relative to one another within a container, (2) there is no restriction on the orientation of the containers relative to one another within a stack, (3) there is no restriction on the orientation of containers between stacks, and (4) there is no required separation between stacks. MCE of the stack(s) is 32 lbs of HD 1.1 (based on the four warheads in a single container).

f. For containers of AIM-l20 missiles with the WDU-33/B warhead: (1) the missiles must be oriented in the same direction within the container, (2) there is no restriction on the orientation of the containers relative to one another within a stack, (3) there is no restriction on the orientation of containers between stacks, and (4) there is no required separation distance between stacks. The stack(s) is HD 1.2.1 with an MCE of 68 lbs (based on the four missiles in a single container).

g. For containers ofAIM-l20 missiles with the WDU-41/B warhead: (1) the missiles must be oriented in the same direction within the container, (2) there is no restriction on the orientation of the containers relative to one another within a stack, (3) there is no restriction on the orientation of containers between stacks, and (4) there is no required separation distance between stacks. The stack(s) is HD 1.2.1 with an MCE of 76 lbs (based on the four missiles in a single container).

h. Stacks of differing missile and warhead configurations will be separated from each other by a horizontal distance of 100 inches. (For example, stacks of AIM-7/WAU-I0 containers will be separated by a horizontal distance of 100 inches from stacks of AIM-7/WAU-17 containers.)

C8.7.2. Provided the conditions above are met, the storage of mixed AIM-7, AIM-9 and AIM120 air-to-air missile containers (with the warheads specified above) may be sited based on whichever of the following is more restrictive:

(1) Siting the greatest MCE present as HD 1.1 (regardless of whether the greatest MCE is for HD 1.1 or HD 1.2.1), or

(2) Siting the total HD 1.2.1 NEWQD present.

## C8.8. **REFERENCES**.

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8-17. HQ AFSC/SEW Memorandum of 11 June 2003, Subject: "Rationale for Noble Eagle Maximum Credible Events (MCEs)".
8-18. Technical Report "Hazard/Quantity-Distance-Test of AIM 7F/M and AIM 9L/M Missiles in All-Up-Round Shipping Containers," MMWRM-TR-84-M25025C, Rev B, August 1985, Ogden Air Logistics Center, Hill, Air Force Base, Utah.

# C9. CHAPTER 9

## OTHER NON-STORAGE RELATED PROTECTIVE CONSTRUCTION

C9.1. **GENERAL**. This chapter will capture non-storage related structures approved by the DDESB, that have protective construction features associated with them but do not fall in the categories associated with the previous chapters.

### C9.2 SECURITY ALERT FACILITY

DDESB-KT Memorandum of 12 March 1976 provided the following siting guidance for Security Alert Facilities.

a. Sitings at a risk factor of 9W1/3 or greater will be approved on the assumption that hardening against attack by sustained small arms fire will be provided. Presence of, or lack of, conventional barricading will not be a factor.

b. Sitings at a risk factor of less than 9W1/3 will be disapproved unless the submission clearly shows that the exposed security alert facility has been hardened against blast overpressure so that, at the proposed location, personnel will not be subjected to risks greater than for siting approved at 9W1/3, in accordance with subparagraph 3a of the DDESB approval memorandum.

c. Siting of the Security Alert Facilities at the minimum permitted distance of 9W1/3 would expose the security personnel to maximum incident peak overpressure up to 11 – 11.5 psi, which is sufficient to cause disabling injuries and render personnel militarily ineffective, possible at a critical time. Consideration should therefore be given to providing distance separation to about 18W1/3 or an overpressure level of approximately 3.5 psi.

# AP1. <u>APPENDIX 1</u>

## <u>MAGAZINE LISTINGS</u>